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JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

Vol 49 JULY 1947 No. 1

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JOURNAL

OF THE

SOCIETY of MOTION PICTURE ENGINEERS

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JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

Vol 49 JULY 1947 No. 1

REPORT OF THE PRESIDENT*

This is the semiannual report of the president to the members of the Society of Motion Picture Engineers. It is a statement of activities subsequent to the report of D. E. Hyndman, past-president, and John A. Maurer, engineering vice-president, titled "Past and Future Society Activities" as published in the September, 1946, issue of the JOURNAL. This report was compiled as of Apr. 15, 1947.

The Society membership has now reached an all-time high of 2537 members. The cash and the negotiable security assets of the Society stand at $103,793.36 as of March 31, 1947. Your past-president, D. E. Hyndman, who is in charge of gaining sustaining memberships has reported $14,850.00 received thus far in 1947. It is hopefully expected that this amount will be increased by several thousands of dollars. The present successful status of the Society places upon the Officers and Board a well-appreciated responsibility of continuing the advancement and success of this great work.

As president of the Society of Motion Picture Engineers, I am very happy with the way that the Officers and Committees are functioning. The Convention now in session is indicative of the increasing activity and increasing scope of Society work. In our past experience a good normal papers' program has included about fifty to fifty-five papers. For this Convention there were over seventy-five papers offered. We are also enjoying one of the largest Convention registrations and attendance.

In carrying forward the work of the Society, the Board for clarification has redefined the scope of our work. The Society of Motion Picture Engineers is interested in and will participate in all technical phases of pictorial rendition of action, whether it be from film as in motion pictures, electronics as in television, or other device. The

* Presented Apr. 21, 1947, at the opening session of the 61st Semiannual Convention of the Society in Chicago.

Society and its engineers have in the published works of the JOURNAL most of the information now required in the art of television, for pictorial recording, trick photography, projection, color, editing, test films, lighting, and studio techniques. This and all other information of the Society are to be applied to this now-expanding art. The Society is not now and does not contemplate overlapping in the activities of other societies in the fields of radio and radio transmission.

As most of you know, Paul J. Larsen and representatives of the Society of Motion Picture Engineers have appeared before the Federal Communications Commission and during 1945 and 1946 obtained for the motion picture industry frequency allocations for theater television use. On petition of other interests the FCC issued Public Notice No. *97615* on Oct. 22, 1946, calling for a rehearing and reallocation of these frequencies to the exclusion of theater television. After a discussion with Eric Johnston, of the Motion Picture Association, Byron Price, of the Association of Motion Picture Producers, Inc., Donald Nelson, of the Society of Independent Motion Picture Producers, Inc., and Y. Frank Freeman, chairman of the Research Council, the SMPE submitted a brief and Mr. Larsen again appeared before the FCC at its hearing on Feb. 4 of this year. The Society received telegraphic support from both Mr. Johnston and Mr. Nelson.

It is the hope and belief of those familiar with these deliberations that action favorable to the motion picture industry will be handed down. It is also the opinion of those close to this work that the right of this industry to these frequencies will again be challenged unless this industry expresses a sincere interest in theater television. The Society is therefore calling this subject to the attention of top representatives of the motion picture industry and asking that they assume future responsibility in this regard.

The Society is carrying forward the standardization program previously undertaken. This includes conversion of war standards into American Standards and a new activity whereby the Society, as a member group of the American Standards Association, is to co-operate in the activities of the new International Standards Organization recently established by the United Nations Organization.

The Society and the Research Council of the Academy have established a co-operative program for the production and sale of test films. In the future all picture and sound test films for 35-mm and 16-mm equipment are to be released under a joint SMPE and

Research Council banner. These test films may be purchased from either the Research Council or the SMPE. This move has been made in order to avoid duplication of effort and to serve the industry better.

By action of the Board of the Society, the 62nd Semiannual Convention which is to be held at the Hotel Pennsylvania, New York, Oct. 20 to 24, inclusive, will emphasize theater engineering. There will also be a comprehensive exhibit and demonstration of theater material and equipment having new features of engineering interest.

Respectfully submitted,
LOREN L. RYDER, *President*

A COMBINATION SCORING, RERECORDING, AND PREVIEW STUDIO*

DANIEL J. BLOOMBERG,** W. O. WATSON,** AND MICHAEL RETTINGER†

Summary—*This paper discusses the construction of the new Republic Productions scoring stage and includes a description of the electrical equipment used for the recording of music. In the building of the stage, which is probably the largest scoring studio in the world, aesthetic elements were given equal consideration with acoustic factors.*

It was also deemed important that the enclosure contain all of the necessary facilities for music recording, such as a dual-reverberation chamber with a remotely controlled door, a vocal room with a large window between it and the stage, two monitoring rooms with concealed speakers, a conductor's podium, and an efficient air-conditioning system.

During the past three years, increased production schedules at Republic Studios demanded additional music recording facilities. Since the original scoring stage, built in 1938, was a combination dubbing and scoring room with compromises in acoustics, it was decided to provide an entirely new and, if possible, an ideal music recording studio. The importance of such an enclosure had always been minimized in the industry, resulting in either multipurpose or converted production sound stages. Because of this attitude, no music recording stage of appreciable size had been designed and built with the primary object

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* Presented Oct. 21, 1946, at the SMPE Convention in Hollywood.

** Republic Studios, North Hollywood, Calif.

† RCA Victor Division, Radio Corporation of America, Hollywood.

of a finished scoring stage, combining all associated requirements. It was therefore intended that the new stage should overcome the shortcomings of what had gone before and should, in addition, provide new and original conveniences for producing better, that is, more efficient and more natural, music recordings.

In keeping with the modern trend in architecture, to combine the aesthetic with the functional, careful consideration was given to the appearance of the stage as a whole. It was felt that it would not be sufficient to provide just a space for the accommodation of an orchestra since this was what all the other stages had done. If the musicians were to be treated as artists, which certainly they were, it was essential to provide an environment which, instead of being unsightly and depressing, should be attractive and inspiring. Certainly, if the boiler

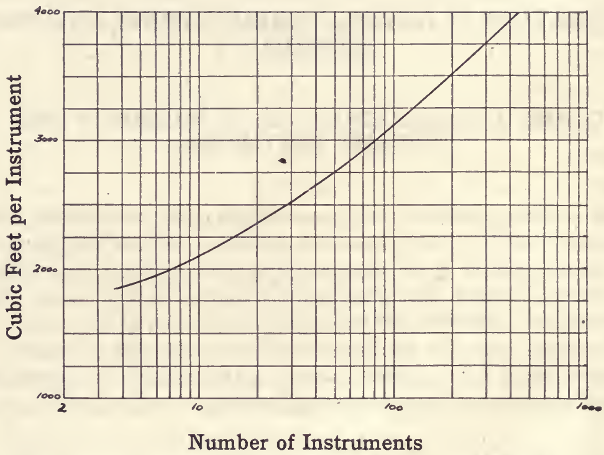

FIG. 1.

room of an aircraft plant could be painted in an attractive color scheme the scoring stage of a motion picture studio could be made clean-cut and appealing. This is no idle repetition of an unimportant trifle, but a serious report which considered not merely the physical, but also the equally important psychological factors which go into the making of a sound track.

When the scoring of music is the primary purpose of such a room (as it was in this instance), it is essential to determine first the number of musicians which such a room is, on the average, to accommodate. Fig. 1 gives the number of cubic feet per instrument which, according

to experience, a scoring stage should have to provide satisfactory results. If this allotted space is less than indicated on the figure—or as on extreme case, if a large orchestra is placed in a small room—the lack of comparatively long-time reflections becomes easily evident. Music tends to lose definition (because of the excess number of short-time reflections) and is then spoken of as "blurred" or "cramped". Placing a small band in a large room is not nearly so objectionable, because a few "flats" or sound-reinforcing panels stationed around the musicians quickly lend to the music the desired character.

For a mean capacity of 70 musicians, the cubical content of the scoring stage therefore comes close to 210,000 cu ft. Having determined the volume, the matter of deciding on the dimensions of the room came next in attention. Since the length of the stage was fixed

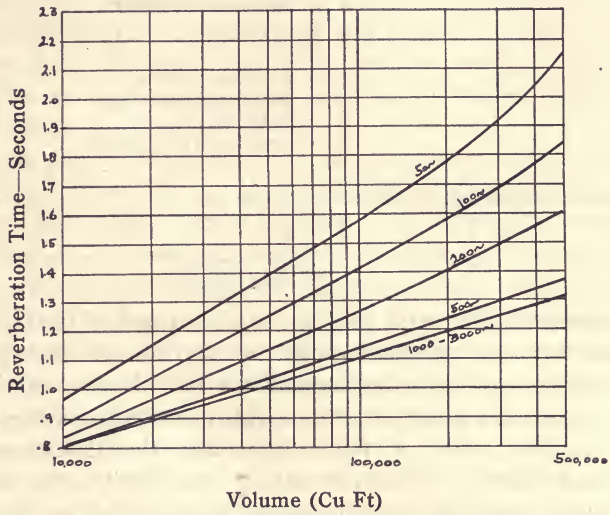

FIG. 2. Reverberation time versus volume.

by the available space (112.5 ft), and since it was desired to make the stage part of a three-story building, the height and width finally selected for the room were 32 ft and 72 ft, respectively. This permitted the construction of a vocal room and a reverberation chamber as adjuncts to the orchestra shell, thereby providing the stage with the desired 210,000 cu ft of volume. The mean height, width, and length of the stage (on account of the configuration of the confines of the stage) are 29 ft, 64.5 ft, and 112.5 ft, respectively, which conform closely with published data on the subject. It should be emphasized,

however, that blind adherence to "optimal-ratio" recommendations may give rise to considerable difficulties in the product. The most important consideration in regard to the proportions of a room must be the purpose or purposes to which it is to be put. The reverberation time at 1000 cycles for a recording studio of 210,000-cu-ft volume should be 1.15 sec (see Fig. 2); hence the mean absorption of the room (the interior surface of which is 24,000 sq ft) can be determined by the equation

$$-\log_e (1 - \alpha) = \frac{0.049\,V}{TS}$$

$$= \frac{0.049 \times 210{,}000}{1.15 \times 24{,}000}$$

or

$$\alpha = 0.31$$

where

$$\alpha = \text{mean absorptivity}$$
$$= A/S$$
$$A = \text{total absorption}$$
$$S = \text{total interior surface}$$
$$V = \text{volume}$$
$$T = \text{reverberation period.}$$

Hence the total absorption can be computed to be

$$A = \alpha S$$
$$= 0.31 \times 24{,}000$$
$$= 7440 \text{ sabines.}$$

Next in importance to the total absorption required in the room at 1000 cycles come the questions of the distribution and the type of the sound-absorbent and reflective materials within the enclosure. Here we have to consider some factors less easily circumscribed by mathematical notation. One of these deals with the allocation of the acoustic and reflective materials within the "shell". In the early days of sound recording (and broadcasting as well), the "live-end—dead-end" studio was almost universally employed. Such a room leaves much to be desired, however. Admittedly, the band is situated in surroundings of considerable localized reverberation, thus providing the type of environs much appreciated by musicians. However, multichannel recording setups began to appear, by means of which a sound track may be made for each of a group of instrument sections. Also, multiple-microphone pickup conditions proved desirable, whereby a mixer blends the individual sections for the purpose of achieving a particular "blend" or "balance". For these two cases the live-end—dead-end studio was found inadequate.

At first consideration it would appear that one microphone would facilitate the mixer's work, in that a considerable tone fusion, existing at some distance from the instruments, would ensure instrument balance. However, this is not necessarily true since a microphone is a monaural device without the ability to select and reject sounds as the human ear does when a listener is concentrating. Therefore, in order to maintain the definition experienced by a person listening with both ears to an orchestra, the single microphone would have to be placed closer to the source of sound. With a short microphone distance the element of balance between the different instrument sections becomes quite critical. The use of multiple microphones, however, obviates the necessity for such critical placement, but selective pickup of a more or less evenly spread-out orchestra can be obtained only if the shell itself is not too live. Indeed, the more microphones are used, the deader should be the shell. If it is then desired to add a reverberatory character to the recording, this can easily be done in rerecording by making use of the reverberation chamber with its adjustable reverberation characteristic.

It must also be remembered that the ratio of reflected-to-direct sound at the microphone—controllable by changing the microphone distance—has a pronounced influence in providing an impression of reverberatoriness (there is no other word for this sensation, "reverberation" being not sufficiently expressive of the continuous sound-reinforcement during transient signals). Hence, if an instrument section as heard through the microphone requires more of this quality, this can be secured easily by increasing the distance. The nicety of this adjustment is considerably greater than that which can be achieved by controlling the acoustics of certain sections of the shell. The chief advantage of such a "subdued" shell lies therefore in the fact that there is less acoustic spillover from one instrument section to another. It should not be thought, however, that this shell is "dead"; far from it; its absorbent and reflective wall sections are approximately equal. On the other hand, the so-called "dead" end is no longer so absorbent, but exhibits a comparatively large area of reflective convex splays. The round-the-room reflections—so often discussed in the literature and so little heard in practice—are thereby noticeably increased, as befits the music of a large band usually heard in a spacious auditorium which by conventional construction favors such long-time reflections.

There is another reason why the live-end—dead-end studio should

be avoided. Acoustically speaking, such a studio is no longer a room, but merely three walls, a ceiling, and a floor, because reflections from the fourth wall (the dead-end) are noticeably absent. Such a condition gives rise to an irregular decay characteristic which does not lend a pleasing character to the recorded music. Fig. 3 shows the reverberation characteristic of the stage as measured with a high-speed level recorder. Next in importance come the shape and the material for the room. Shape and material cannot be divorced from each other, because the material frequently influences (and in no minor manner) the shape or contour of the walls and ceiling. For instance, if convex reflective splays (so-called polycylindrical diffusers) are employed as part of the interior treatment, it makes a considerable difference in the required number of such splays whether they are made of plaster or of plywood. If made of plaster, fewer will be required than when made of plywood, because, with practical thicknesses of plywood and plaster, the plywood splays will be more absorptive at practically all audio frequencies than the plaster splays.

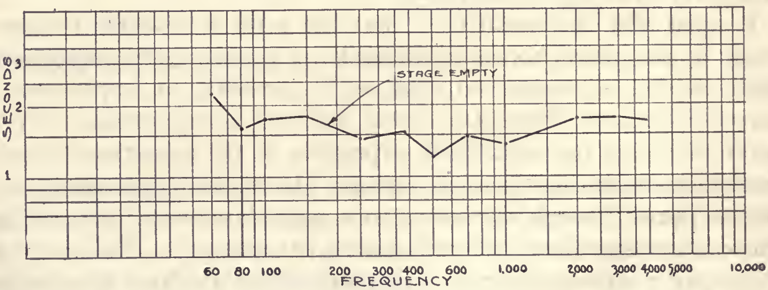

FIG. 3. Reverberation characteristic of Republic Studio scoring stage No. *12*.

Regarding the shape and the configurational details of the room, it was thought, early in the period of planning, that cylindrical wood splays would prove desirable for the band-shell contours as well as for the side wall and ceiling of the stage outside the shell. Their plentiful use in another, smaller stage had given ample evidence of their effectiveness—their pleasing tonal response, their high dispersion capacity, and their great absorbent qualities at the low frequencies.

Fig. 4 shows the plan of the stage, and Fig. 5 its elevation. A number of salient features at once will be evident. The shell, of trapezoidal shape, and of a depth amounting to practically half the length of the stage, affords easy accommodation of orchestras ranging

from 20 to 100 instruments. The permanent three-riser platform extending in an arc across the entire width of the shell represents a desirable construction in a stage of this size. It not only simplifies greatly the arrangement of an orchestra, but provides easily accessible outlets (at the steps) for microphones, headphones, and music stand lights and thus reduces hazardous cables laid across the floor. The shell is confined by painted splays and panels of absorbent material laid with smooth joints and rough outside surface. It is

FIG. 4. Floor plan of stage.

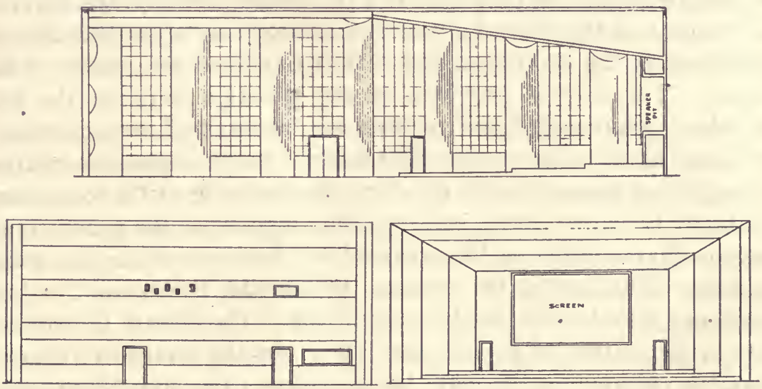

FIG. 5. Elevation of stage.

lighted without glare by reflector-type, flush-mounted fixtures with diffusing lenses, and altogether conveys a pleasing impression without appearing overluxurious.

Adjoining the stage are a reverberation chamber and a vocal room. A reverberation chamber provides a very necessary adjunct for sound-on-film recording, the occasions being indeed numerous when a reverberatory quality is to be added to a recording during or after its completion. Briefly described, the process consists in reproducing sound in a highly reverberant room—the so-called reverberation chamber—and mixing the output from a microphone in this room with the original recording by a method known as "dubbing" or "rerecording". Surprisingly, when the electric level of the "reverberated" signal is as much as 20 db below the electric level of the original recording at the mixing panel, the combined reproduced signal conveys a strong impression of reverberatoriness in every syllable of speech or passage of music.

Unlike other electric or mechanical means of adding a reverberatory note to a recording, the chamber method provides both the proper growth characteristic and the decay quality of sound in a live enclosure. Delay networks, magnetic-tape recordings, and other devices for achieving synthetic reverberation usually permit only the provision of the decay characteristic; no attempt is made to introduce the growth characteristic.

By dividing the chamber into a small and a large room, two different characters of the reverberated signal may be had by placing the microphone in either one or the other of the enclosures (assuming each has been equipped with a loudspeaker for reproducing the signal). By proportioning the dimensions of the rooms carefully, the spectral distribution of the normal modes of vibration can be made decidedly differerent in the two rooms and with it, of course, the quality of the signal. If a door is provided in the partition between the two chambers, additional signal qualities can be obtained by reproducing the signal in the room opposite that in which the microphone is located. By adjusting the opening of the door, the character of the sound may gradually be varied over a considerable range, since the sound-transmission characteristic of the aperture is a function of the size of the opening. The smaller the opening, the smaller the amount of low-frequency sound which can be transmitted. The door in this respect acts in the nature of a high-pass filter. In the dual-reverberation chamber pictured on the plan, the aperture of the door between the two rooms was made controllable from the mixing console on the stage.

The reverberation chambers were built of concrete, and the insides of the rooms were finished with cement plaster to secure as high a reflectivity as possible. The walls, as well as floor and ceiling, were kept nonparallel to avoid flutter echoes in the rooms.

The vocal room likewise represents a necessary facility for the recording of music with vocal renditions. The orchestration and the song, in many of such instances, are recorded on separate tracks chiefly to have some control over the desired "mix" of the two after the respective scene has been photographed, since production requirement cannot always be anticipated fully. Then too, if necessary, either the music or vocal number can be replaced later without trouble because sufficient acoustic isolation exists between stage and vocal room to obtain essentially pure music and vocal tracks. In practice, however, a third sound track is always recorded simultaneously with the other two, which is a "mix" of music and song as deemed best at the time and is frequently the one used in the completed picture.

Such an arrangement requires that the conductor in the scoring stage shall be able to listen to the volcalist as well as to the orchestra. He will, therefore, be required to wear one earphone connected to the vocal recording channel, while the singer may either wear earphones connected to the music recording channel, or else listen to the music reproduced in low tones over a public-address system installed in the vocal booth.

The director's podium is mounted on rubber-tired casters with a jack-type brake to prevent its moving when in use. The podium is provided with a public-address system connected to the mixer and to the vocal room, and with headphone outlets with volume control. Indirect lighting is provided from a hooded fixture across the entire width of the podium, in addition to speed lights and an electric stop clock.

During postscoring with a picture on the screen for cuing, the stage lighting is usually off; to enable the musicians to see the director, a spotlight in the ceiling is directed at the podium, resulting in ample light on the director without causing any glare.

Two rooms, 7 ft by 30 ft each, back of the screen and across the entire width of the stage, provide storage space for chairs, music stands, and instruments. A 7- by 5-ft room located at one end of the vocal room is equipped with cabinets for microphones and headphones, and cable hooks for all cables when not in use on the stage.

The scoring monitor room is accessible from the stage proper and

has good visibility over the entire stage and vocal room. It was felt that a large room was desirable to preclude the necessity of low monitor volume levels, which usually results in loss of perspective and good orchestral balance. The monitor speakers (low-frequency and high-frequency horns) are mounted flush in the wall opposite and directed toward the mixer. The mixer console is placed adjacent to the viewing window of triple plate glass set at dissimilar angles. The interior finish of the monitor room is comparable to that of the stage. Polycylindrical splays are provided in sequence on one side of the enclosure, with the remainder of the walls finished in acoustic tile and acoustic plaster.

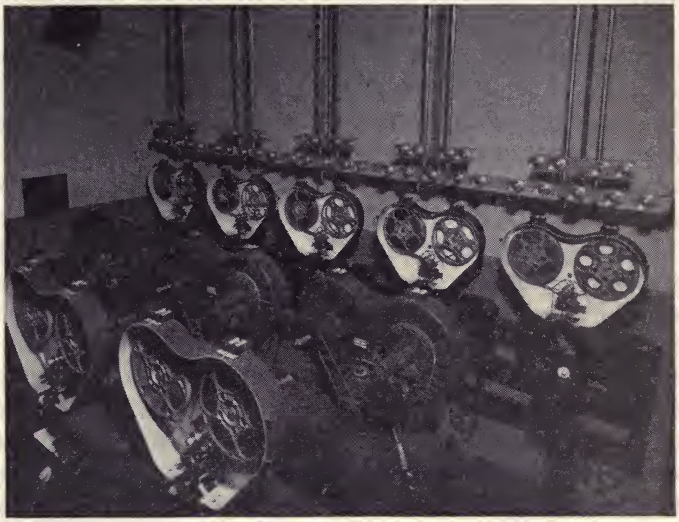

FIG. 6. New machine room.

The original installation[1] of the fixed recording equipment consisted of two complete recording channels. One was normally used for dubbing and the other for scoring, although both could be employed for two-channel scoring sessions. Eight soundheads, two film recorders, an acetate recorder, and the amplifier racks, located in one room, comprised the installation.

It was thought that more equipment was necessary, with certain refinements that would provide greater flexibility. The original eight soundheads, therefore, were moved to an adjoining room and eight new heads were added (Fig. 6). Fig. 7 shows the floor plan of the film

machine room. Sixteen film reproducers are located in the room with five machines along each side wall and three pairs of machines, back to back, in the center of the room. Three gutters mounted in the walls behind the machines carry the speech lines, the exciter lamp supply lines, and the interlock and rewind power lines. Loop racks are installed over the machines located along the walls. These provide ten reproducers with loop facilities. Each machine has a combined feed mechanism and electric rewind magazine as shown in Fig. 8.

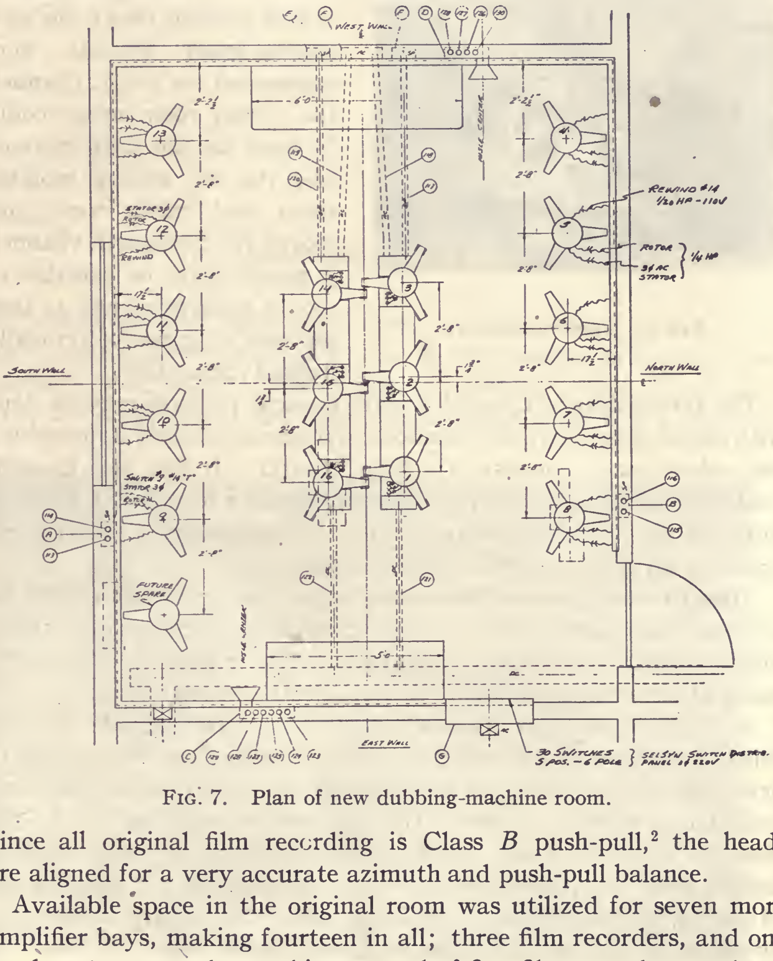

FIG. 7. Plan of new dubbing-machine room.

Since all original film recording is Class *B* push-pull,[2] the heads are aligned for a very accurate azimuth and push-pull balance.

Available space in the original room was utilized for seven more amplifier bays, making fourteen in all; three film recorders, and one fixed acetate recorder, making a total of five film recorders, and two fixed acetates. With four complete recording and monitor channels

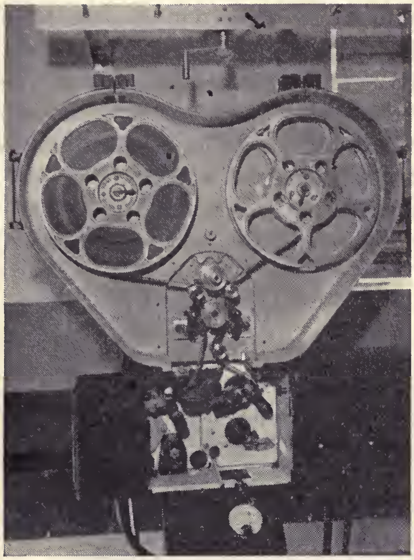

FIG. 8. Film reproducer.

available, it is possible to record a musical on four separate channels. With the use of sound trucks, additional channels can be obtained. This possibility was given consideration in the design of the mixer consoles for the monitor room and the review room. It was thought that if the new scoring-mixer console were engineered for a split channel, the review room mixer could be used for the third channel and the old scoring monitor room and mixer were employed for the fourth channel, it would thus be possible to record with from one to four separate channels of centrally located apparatus.

The rerecording of Class *A de luxe* musical pictures may be done with better perspective and balance in a room more nearly approaching the volume and acoustics of a large theater. It was also thought that rerecording activities could be expanded by installing a dubbing mixer on the new scoring stage. Thus by adequately equipping our facilities, all production schedules could be met.

After the requirements for scoring and dubbing had been carefully analyzed, schematic diagrams were planned to provide complete flexibility without unnecessary equipment. Fig. 9 shows a block schematic of the scoring channel in a typical split-channel setup.

A cabinet rack is provided adjacent to the mixer console; it contains 12 microphone preamplifiers and four single-stage booster amplifiers to be used for isolation amplifiers or where additional gain is required in low-level circuits. One headphone amplifier (RCA *MI-9354*) is available which can be fed either from the vocal channel bridge buss for prescoring or from a soundhead for postscoring. Metering facilities, in the form of a meter and rotary switch, are provided for all plate and filament circuits in the rack.

The patch bays are divorced from the mixer console, and high-

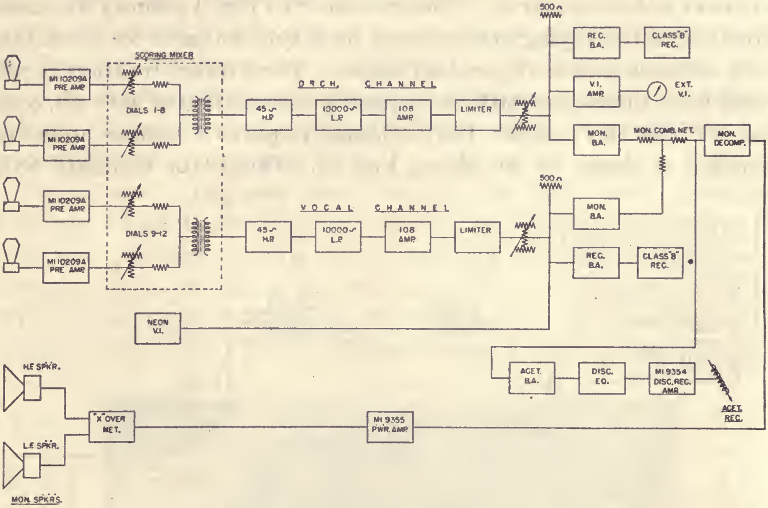

FIG. 9. Schematic of scoring channels (split).

and low-level patch bays are located in this cabinet rack. The mixer console, placed as shown in Fig. 10, commands a full view of the stage and vocal room. The console is equipped with a 12-position mixer that may be split into two channels of eight and four each with

FIG. 10. Scoring-mixer console.

a master volume control. The schematic in Fig. 11 shows the mixer circuits and the keying arrangement for a split mixer or for combining both sections into a 12-position mixer. Each mixer position is provided with three-position low-frequency attenuation of zero db, 5 db, and 7 db at 100 cycles. Each channel requires a volume indicator installed as shown in the photo, Fig. 12. One is the standard RCA

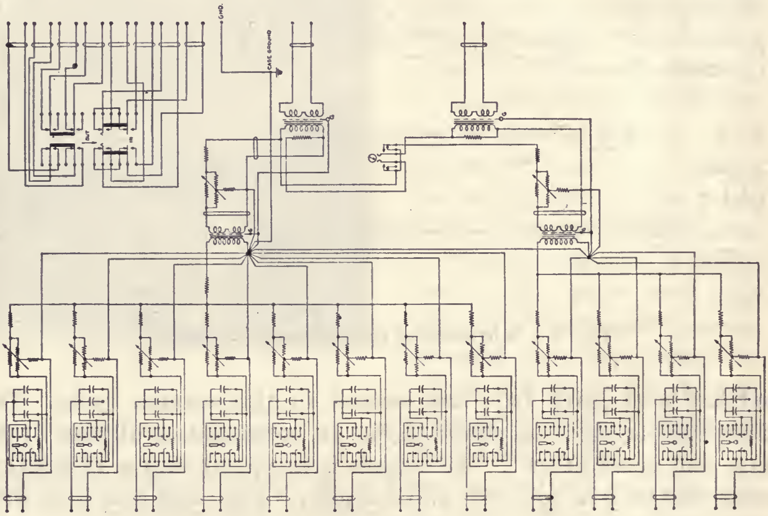

FIG. 11. Schematic of scoring-mixer circuits.

neon volume indicator and the second indicator is a vacuum-tube meter with fast attack timing (60 milliseconds) and slow delay timing (0.5 sec), which was developed by the Republic Sound Department. Volume-limiter ceiling controls for the two channels are located at the right side of the mixer panel, and on the panel to the left of the mixer panel are mounted the p.a. signal and intercommunication controls. Two-way p.a. communication is provided to the music director, the stage proper, the vocal room, the recorder, the projection room, and the film machine room.

The p.a. microphone and speaker are mounted in the vertical section of the console in front of the mixer. The panels on the top surface of the console are pivoted for accessibility. Doors are provided on the ends and front of the console to expose the internal wiring to the local terminal blocks.

Speech circuits located in the scoring stage are terminated in the cabinet rack. The transmission lines to the main amplifier room are

composed of No. *19* twisted pair lead-shielded cables in 2-in. conduits which are placed low enough in the ground to give maximum safety against any future grading or ditching for underground lines. The conduits are laid between stages *9* and *12* and are approximately 225 ft long. The conduits carrying circuits intended for a particular rack are terminated behind that rack.

Fig. 13 shows the rack layout of the new installation. One new rack was added to the left end and six new racks were added to the right end. In amplifier bay No. *1* are two *MI-9328* amplifiers with a total gain of 100 db, which are used to increase the output of the *MI-4875* pickup to 0-db level for feeding the monitor amplifiers of the acetate playbacks. Nine phototube preamplifiers for the new

FIG. 12. Scoring console.

soundheads are so mounted on shelves that the plugs on the amplifiers line up with receptacles on the shelf assembly and engage when set in place. Two volume compressors for the dubbing channel are also included in this rack. A patch bay is provided where all speech circuits in this rack and trunk lines to other points appear.

Bays *2*, *3*, *4*, and *5* were not changed except for the additon of trunk lines to other new bays. Bay *6* was allotted for additional circuit laboratory facilities and test trunks to all new amplifier bays, mixer consoles, projection rooms, and other apparatus. On bay *7* is channel No. *3* or the normal dubbing channel for stage *12*. This channel is also used for the second channel on split or dual recordings. In bay *8* is channel *4* or the normal scoring channel. Bay *9* houses the monitor amplifiers and the decompensator for channel one. Bay *10* carries

the monitor amplifiers, *etc.*, for channel *2*, and bays *11* and *12* contain the monitor amplifiers, *etc.*, for channels *3* and *4*, respectively. In bays *11* and *12* are also mounted two *MI-9354* amplifiers, of which one is used for a headphone amplifier for the output from the orchestra channel bridge buss for split-channel operation; the other is used for orthoacoustic recordings.

In bays *13* and *14* are the main signal system patch panel and the p.a. switching panels. The signal system may be patched to include only those positions (mixer, recorder, projection, machine room) which

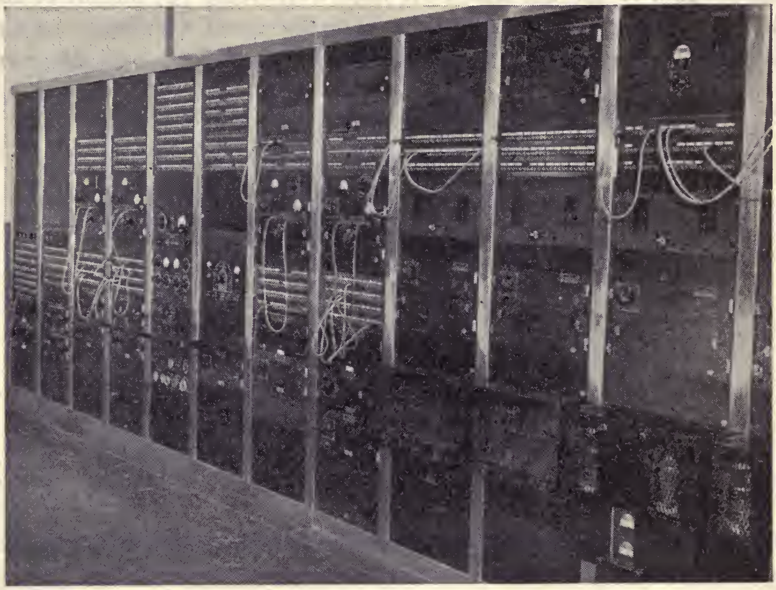

FIG. 13. Amplifier racks, new installation.

will be required to operate together during a recording session and are not to interfere with any other independent unit operating on either of the two stages. The signal lights are "recorder ready", "machine room ready", "projection room ready", and the "running" lights. Thus, all positions operating as a unit have visual indication when all positions are ready and when on a "take". The running light circuit also controls the red warning lights at each entrance of the stage.

The p.a. switching panel selects p.a. circuits for the entire installation consisting of 15 stations. Each station terminates at a designated rotary switch which selects the desired p.a. amplifiers and buss,

and also the relay keying circuits. Five p.a. amplifiers and busses are provided so that five different systems may work simultaneously with no cross talk. The selector switches of stations that are to communicate together are set to the same p.a. buss and nonassociated p.a. networks are set on other p.a. busses. This arrangement has proved very flexible and foolproof since the setup operation is rather simple,

One standard film recorder and two Class *B* push-pull film recorders have been added to make a total of three Class *B* recorders and two standard recorders. Each recorder position has its associated p.a. signal and interlock control panel mounted in an inclined panel on the front of the recorder table. Behind each recorder, mounted flush in the wall, is the combination p.a. and monitor speaker with individual volume control.

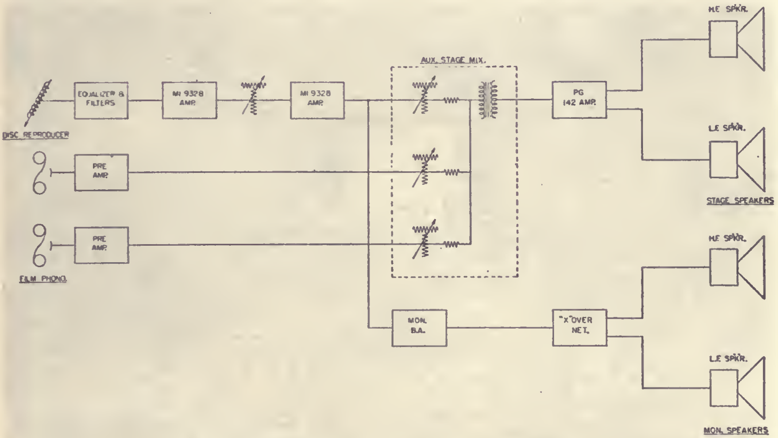

FIG. 14. Schematic of playback system.

An additional disk recorder provides facilities for two scoring sessions or for two acetate copies when needed. A transfer switch on the recorder control panel selects the record position or the payback position. Playback reproduction is through the normal monitor circuits and through an auxiliary mixer on the scoring stage Fig. 14 shows the block schematic of the playback system.

All filament and plate requirements are supplied from rectifier units mounted in the power room. The filament supply units are dry-disk rectifiers and the plate-supply units are of the tube-regulated type. No line-voltage regulators are used since the main supply is fed from

an isolated bank of transformers and the line voltage is constant within plus or minus 3 per cent.

Two new Selsyn distributors have been added, making the total four, with space and load requirements allotted for a fifth, should it be needed.

The interlock selector switch[3] panel is located in the film machine room. A total of 30 Selsyn motor circuits located in both stages *9* and *12* are controlled by the 30 selector switches which have five positions so that one or more motor circuits may be connected to any of the four present distributors. The positions on the switch may be selected prior to closing the contacts, thus eliminating the danger of moving the switch past a live buss. The distributor control circuits are patched to the selected control stations by patch cords.

FIG. 15. Dubbing console and scoring stage.

The dubbing console located on the new stage (Figs. 15 and 16) was designed to incorporate the features that were found desirable from past experience. A 12-position mixer was expanded into three panels of four positions each, physically so spaced to allow three mixers sufficient elbow room. The main dialogue equalizer panel located between the center and right-hand panels may be operated either by the first or second mixer, or an extra man seated between the first and

second mixer. The console provides room for four mixers, if that many are needed. A three-position auxiliary mixer is located between the center panel and the left-hand panel and may be operated by the mixer at either panel. The auxiliary mixer is used for reverberation or other effects. Soundhead amplifier outputs are bridged by zero-db-gain bridging amplifiers and fed to the auxiliary mixer pots, thence through a suitable amplifier to the speaker in the reverberation chamber. The reverberated signal is picked up by a microphone and fed to one of the main mixer pots, where it is mixed with the original for the desired effect. Fig. 17 is a block schematic. The remote control for the door between the two reverberation chambers is located

FIG. 16. Rear view of scoring stage.

in a panel adjacent to the left-hand mixer panel and is calibrated in degrees of door opening. Practically unlimited effects of reverberation may be obtained by the several variables, such as speaker placement, microphone placement, levels employed, varying door opening between chambers, and equalization of both the signal fed to the speaker and the reverberated signal. Four RCA *MI-10102* compensators are located within easy reach of the mixers and are used for auxiliary equalization.

The main dialogue equalizer panel located adjacent to the right-hand mixer has six control knobs and will produce almost any type of

compensated-frequency characteristic desired. A variable high-pass filter is provided with five different cutoff frequencies, namely, 80, 100, 120, 135, and 150 cycles. A variable-dip equalizer is available with five resonant frequencies of 1500, 2000, 3000, 4000, and 5000 cycles, having five steps of 2 db each. The low-frequency attenuation is controllable in eight steps of 2 db at 100 cycles by rotating a knob counterclockwise from the zero position. Clockwise rotation from the zero position gives equalization in six steps of 2 db at 100 cycles. An attenuator with converse attenuation is connected to the same control shaft and maintains constant insertion loss outside the equalized portion of the characteristics. High-frequency equalization is controlled by two knobs, one for the amount and the other for the frequency band. Equalization may be had at resonant frequencies of

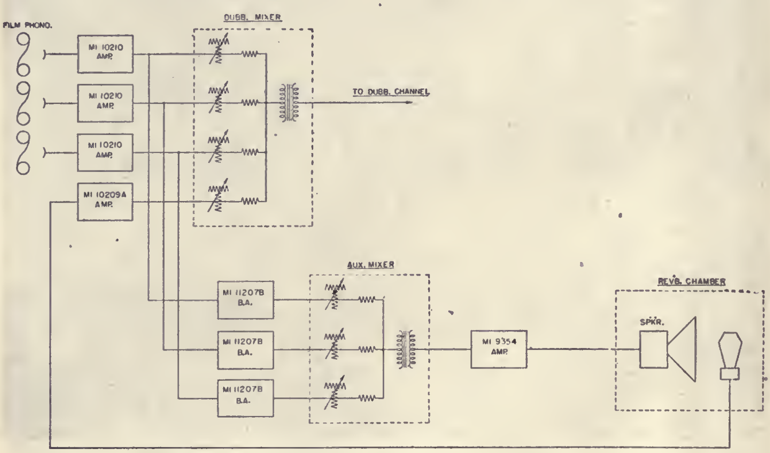

FIG. 17. Schematic of reverberation channel.

3500, 5000, or 8000 cycles in six steps of 2 db each by clockwise rotation of the high-frequency control and by selecting the resonant frequency required. Constant insertion loss is also maintained for this equalizer. High-frequency attenuation is provided by counterclockwise rotation of the high-frequency control in six steps of 2 db each at 6000 cycles. Curves are shown in Fig. 18.

The total insertion loss of the complete equalizer is 24 db, which is compensated for by an RCA *MI-11207A* amplifier. Any one or all of the equalizers and filters may be patched through a key located on the panel and may be keyed in or out of the circuit for preset amounts

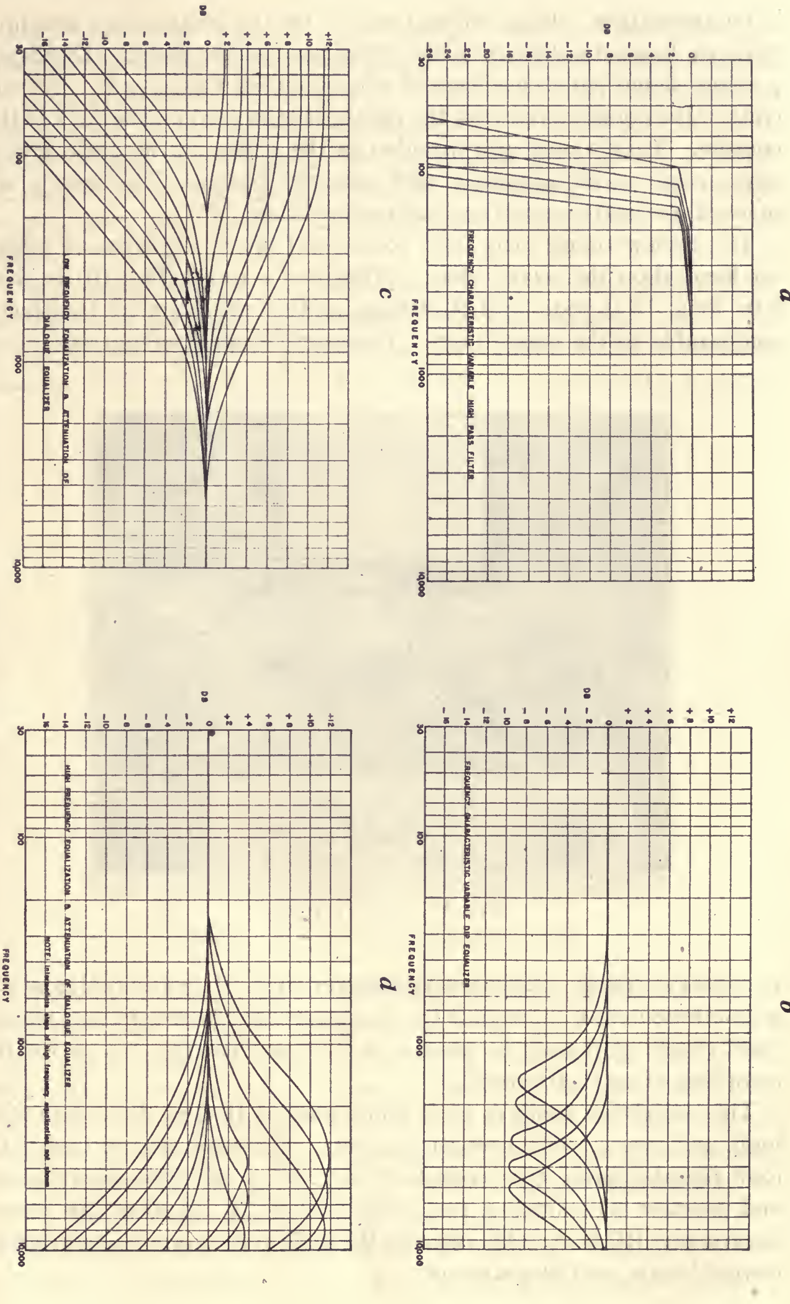

FIG. 18. Frequency characteristics of dialogue filter and equalizer.

of compensation. Four ceiling controls for the compressors and limiters are located adjacent to the right-hand mixer panel. Duplicate p.a. and signal panels are located at each end of the console. All circuits in the console appear in the patch bays located on the back of the console. Panel doors are provided in the ends and the back, giving easy access to all apparatus and terminal blocks. The panels are pivoted for ready inspection and maintenance.

The review room, projection room, and music department offices are located on the second floor. The review room (Fig. 19) is 26 ft 6 in. long, 15 ft wide, and 10 ft high, and carries acoustic treatment comparable to the main stage. Two-way corner speakers were used

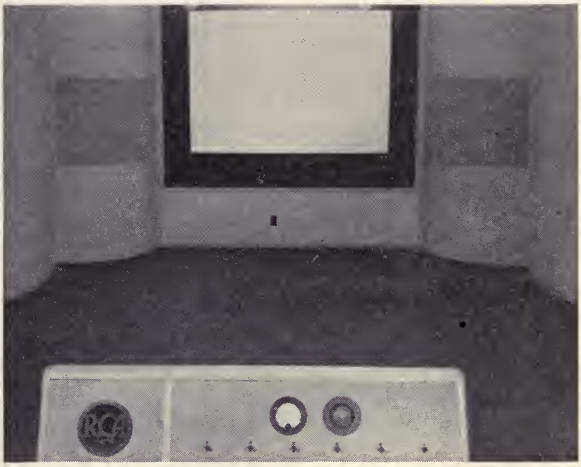

FIG. 19. Review room.

to conserve space. A six-position mixer with *VI*, p.a. signal, and intercommunication shown in Fig. 20, is provided for music and effect-track checking or may be used as a third scoring channel or for re-recording of up to six tracks.

The projection room is 15 ft wide, and 26 ft 6 in. long, and 9 ft high, and treated with acoustic plaster. The room is equipped with four Simplex projectors complete with RCA *MI-9066* soundheads and preview attachments, two additional RCA *MI-9066* film reproducers, one RCA *PG-142*, and one RCA *PG-140* reproducing system, rewind bench, and film storage.

The *PG-142* and two projectors were provided for the main stage to allow continuous showing, although the prime use of the stage is the scoring of music. Electric rewind attachments on the projectors eliminate lost motion during rewind operation. The soundhead output is normally connected for fader operation through the *PG-142*, but may be keyed through a preamplifier and sent to the scoring console for cuing and through the headphone amplifier to the stage phones.

The preamplifiers and low-level patch bays are mounted in a cabinet flush with the wall adjacent to the *PG-142* amplifier rack. The p.a. signal and intercommunication panel is mounted flush in the wall between the two projectors. The *PG-140*, two projectors, and the

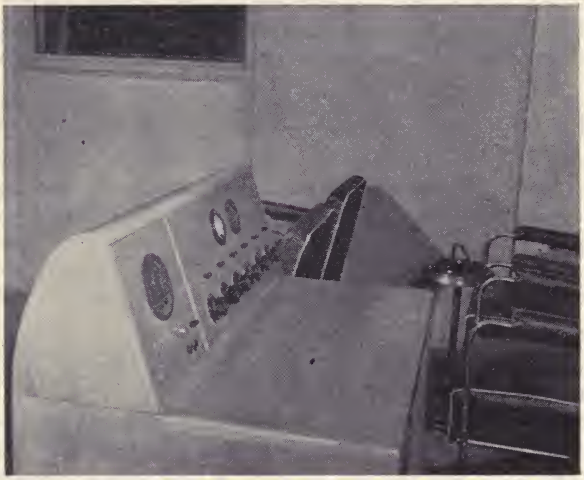

FIG. 20. Mixing console of review room.

two film reproducers are provided for the review room where continuous shows may be run. However, since the review room is used almost exclusively for checking music and effect tracks, the soundhead outputs are normaled to preamplifiers, whose output is fed to the review room mixer and thence to the *PG-140* and review room speakers. Since the projectors are provided with preview attachments and two film reproducers are available, four tracks may be run in synchronism without additional facilities.

The driving motors are Selsyn interlock, and an interlock distributor panel is located in the booth. Thus, if every machine is available,

it is possible to interlock them and to run the outputs from six tracks to the review room mixer. The Selsyn system may be reversed for stop, go, and reverse runnings. The reversing switch is incorporated in the lock switch, which is a three-position switch. One position is for lock on the foward-running position, the center position is off, and the third position is for lock in the reverse-running position. All take-ups are modified for reverse-running. Low- and high-level lines between the projection room and monitor room, dubbing console, and main amplifier room are provided. Because of the close contact required between the sound department and music department, both departments were installed in this building. The sound department has offices on the first floor, as has the music library. The music department offices are located on the second floor, and since the review room is also there, any picture reviewing necessary by the music department may be done without lost time. The third floor is reserved for future expansion.

Leading artists, such as Leopold Stokowski and Artur Rubinstein who have made recordings on this stage, praise its excellent acoustic qualities. Tremendous interest has been stimulated throughout the industry for similar structures, and other major studios have negotiated for the use of this scoring stage.

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AN ANALYSIS OF LOW-REFLECTION COATINGS AS APPLIED TO GLASS*

W. P. STRICKLAND**

Summary.—*A brief summary of the development of the low-reflection coating is given. As instruments were improved, a point was soon reached where further improvement in optical design required elimination of surface reflections. An explanation of the color effect observed in a coating and a method of applying a film whose index varies from top to bottom which will eliminate the color effect is described. A comparison is drawn between the coating produced by natural aging, nitric acid, hydrofluoric acid, magnesium fluoride, and the American Optical Company low-reflection coatings. This shows that the magnesium fluoride is the most practical film to date when all factors are taken into consideration. The American Optical method of applying coatings without using vacuum is described. There are four main advantages in using a low-reflection coating: (1) elimination of reflections, (2) increased transmission, (3) increased contrast, and (4) increased chemical stability. Several tests are outlined which indicate that glass properly coated with magnesium fluoride will withstand more chemical abuse than uncoated glass. A new method of removing a high-temperature-baked low-reflection coating using melted crystals of potassium bisulfate is described which will materially speed the decoating process.*

Since the beginning of time, man has striven to improve the tools with which he has to work. The first telescopes were very simple and no thought was given to reflection losses because these difficulties were minor in comparison to the other shortcomings. To increase the speed and quality of various types of lens systems, more lens elements were added, and each additional element decreased the total transmission of the system and decreased the contrast of the image. It was soon found that there was a practical limit to the number of air-spaced elements that could be used in a lens system without encountering serious difficulties with reflections. This was true with camera lenses and to an even greater extent with the many complicated instruments required by the Armed Services. With each improvement in optical design it became more obvious that the reflection problem must be met and treated.

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* Presented Oct. 22, 1946, at the SMPE Convention in Hollywood.

** Simpson Optical Manufacturing Company, Chicago, Ill.

Mr. H. Dennis Taylor, in 1892, was the first to recognize the need for reflection-reducing films. He and many other investigators tried to treat lenses chemically, with only partial success. It was not until Dr. John Strong first used the vacuum process to apply coatings to glass that men began to see a practical way of reducing surface reflections. He placed a quantity of calcium fluoride in a small heater and arranged the glass parts above. The assembly was enclosed within a bell jar and the air removed. The calcium fluoride was then vaporized by the heater, and a thin coating condensed on the glass. Other investigators made refinements on the basic idea, and by 1941 the present process was well under way.

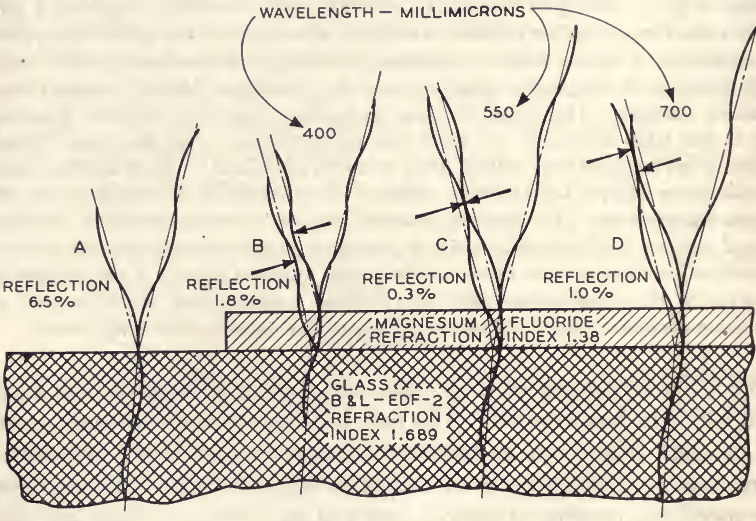

FIG. 1. The effect of light of 3 wavelengths on a layer of magnesium fluoride.

The war emergency took hold at this point and in the short space of five years the coating of glass has become an industry. Today, practically every optical company has coating facilities, and uses for the process are being extended.

Now let us look more closely at the low-reflection film. The most noticeable thing about a low-reflection coating is its color. The average individual usually remarks that the coating is purple. It is discouraging to the coating man that the only comment made on his accomplishment is to mention one of its disadvantages. Seeing that the color of the coating is so noticeable to the user, I would like to

point out the reasons for this effect. Fig. 1 shows a cross-section view of a coated piece of glass. This glass has an index of refraction of 1.69; and the magnesium fluoride an index of 1.38. The thickness of the coating is one quarter of the wavelength of green light. This amounts to a thickness of about 3.8 millionths of an inch. The wave character of light is represented by the wavy lines. In an uncoated piece of glass we would expect about 6.5 per cent reflection per surface, and the balance transmitted as indicated by example *A*. In example *C* the reflected light is broken into two beams of about equal intensity. In this case the thickness of the magnesium fluoride film is one fourth of 5500 A thick. The beam of light reflected from the glass surface has been made to travel one-half wavelength farther before being re-

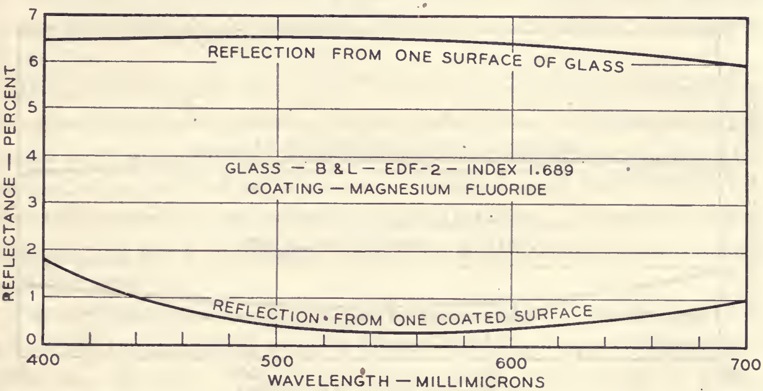

FIG. 2. The reflection values for a single surface of glass coated with magnesium fluoride.

united with the first beam. The two beams will then cancel each other and the result is a reflection of 0.3 per cent. This canceled light must go somewhere, so it appears in the transmitted beam of light. There is another condition that is important in minimizing surface reflections. The two small beams of reflected light must be equal in intensity in order to bring the reflection to zero. In example *C* our result was 0.3 per cent because the reflection from the upper surface was too large. To give zero reflection, the index of refraction of the film must be 1.3 In case *B* we see what will happen to the same coating when violet light, 4000 A in length, is used. The second reflected wave, being shorter than case *C*, will no longer be exactly one-half wavelength out of phase with the first reflected beam. This will result in incomplete cancellation. Example *D* shows a similar condition when red light

of about 7000 A is used. The second reflected beam, being longer than the one in example *C*, will result in incomplete cancellation and a reflection of about one per cent.

From these three examples, it is seen that the color of the coating is caused by the variation of the wavelength of light found in the visible spectrum. Fig. 2 shows a typical reflection curve that could be obtained from a glass with an index of refraction of 1.69 and a magnesium-fluoride film. Along the abscissa the wavelength varies from 4000 to 7000 A. The ordinate is calibrated in percentage reflectance. You will notice that at 4000 A there is a reflection of 1.8 per cent, and as the wavelength increases the reflection drops to a minimum at about 5500 A. The reflection increases again in the red.

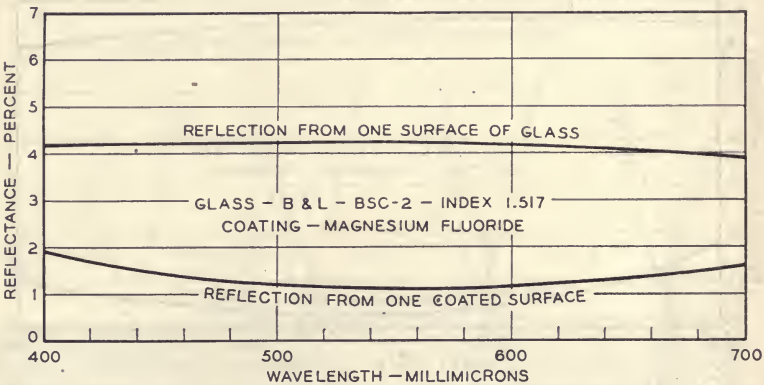

FIG. 3. The reflection values for magnesium fluoride on *BSC-2* glass.

There are two main factors that must be observed to reduce reflection to zero. A coating must be produced so that the two reflected beams of light are exactly out of phase with each other. In addition, the two beams must be of the same intensity. If these conditions are not met, incomplete cancellation of light will result. The surface reflection from an isotropic medium, such as our glass, varies with the index of refraction of the material. To make the two beams equal, it is necessary that the index of the refraction of the coating material be equal to the square root of the index of the glass. Thus, for a glass that has an index of 1.69, the coating material should be 1.3, Unfortunately, there is no suitable coating material with an index of 1.3. If a glass with an index of 1.52 were used, such as common window

glass, the film necessary to produce zero reflection should have an index as low as 1.23. Fig. 3 shows the reflectance value for a magnesium-fluoride film supported on borosilicate crown glass. This shows clearly the result of deviating from the square-root condition.

Many attempts have been made to find a satisfactory substitute for magnesium fluoride. Calcium fluoride, strontium fluoride, lithium floride, sodium fluoride, cryolite, and many other materials have been worked on, but failed because of poor mechanical or chemical properties. Some manufacturers add a small amount of calcium fluoride to the magnesium fluoride, which does reduce its index slightly but again mechanical and chemical properties are sacrificed. Magnesium fluoride can be applied to glass in a spongy or porous form. By applying the coating at higher pressures than recommended, spongy films with an index as low as 1.2 can be obtained. These wipe off readily.

Magnesium fluoride has, so far, proved to be the best coating material, when all factors are taken into consideration. To obtain the best results, however, care must be taken in the preparation of the glass and in the methods of application. The glass must be cleaned to remove fingerprints, grease, and even dust particles. Every spot of dust remaining on the lens during the coating process will result in a small uncoated area.

The equipment for coating is relatively simple. A mechanical vacuum pump connected in series with the diffusion pump is required to secure the vacuum. This is connected to the bottom side of a large steel-base plate which has the appropriate electrical connections.

The magnesium fluoride is placed on a small heater and the lenses are arranged about 15 to 20 in. above. A large lens heater is placed over the lenses and a bell jar is placed over the entire assembly, so that it is sealed tight against the metal-base plate. The lenses are heated to approximately 450 F while the pumps are securing the desired vacuum. After the vacuum has reached about 10–5 mm of mercury, we are ready to apply the coating. The magnesium fluoride is heated until it vaporizes, and being in a vacuum it streams out in all directions much the same as light radiates from a lamp. The fluoride condenses on the relatively cool glass in a thin, uniform layer. Any obstruction that might come between the lens and the fluoride heater would cast a shadow on the glass being coated. The thickness of the coating is controlled by observing the color of sample glass arranged adjacent to one of the lenses to be coated.

This, by no means, is the only way to apply low-reflection film to glass. The natural elements produced the first low-reflection films. These were formed by the action of moisture on the less stable glasses. They were usually spotty and very hard, and not so efficient as our present magnesium fluoride. Many attempts to reproduce these natural films were made by Taylor, Kollmorgan, and Wright. The most successful films of this type were made by Frank Jones, working at Bausch and Lomb. His films were uniform and hard, but not so efficient as magnesium fluoride.

Another chemical method of producing low-reflection film on glass was developed by F. H. Nicoll of RCA. This type depends upon the action of hydrofluoric-acid vapors on glass. This process has advantages over other chemical methods, in that ordinary window glass can be treated in a reasonable length of time. The process can be applied to large plates of glass as well as small. The one disadvantage noticed with this film is that the coating is somewhat uneven. This is not serious, however, and possibly could be overcome.

One of the most remarkable, and indeed the most likely process to challenge the magnesium fluoride, has been developed by Dr. Molten of the American Optical Company. A lens to be coated is cleaned and rotated about a vertical axis at a moderate speed. Several drops of solution are dropped on the lens and allowed to whirl off and dry. This produces a uniform coating on the glass and takes less than one minute. The process can also be extended to large plates of glass by dipping them in the solution. These coatings can also be applied by spraying or swabbing. Films of this type are hard enough to apply to eyeglass lenses and come very close to the efficiency of magnesium fluoride. This type of film looks much the same as magnesium-fluoride films and can be washed and cleaned without damage. It is not oil-sensitive and will stand the 24-hr humidity test and salt atmosphere test of the Frankfort Arsenal Specifications *51-70-4A*. The films are attacked by strong alkalis but can resist acids admirably.

In addition to this film, Dr. Molten has developed another type of coating which has the unusual property of having the same reflection effect on all glasses regardless of index of refraction. A single surface will reflect, after coating, about $^3/_{10}$ of one per cent even on glasses with an index as low as 1.52. This film owes its unusual properties to the fact that the index of the coating material is varied from about the index of air at the air-coating surface to about 1.5 at the glass-coating surface. The spongy nature of this coating makes this film

soft and oil-sensitive, but owing to its remarkable properties, man uses will be found for it.

Efforts to replace magnesium-fluoride film with chemical films hav failed because nothing has been found with the abrasion-resistin quality of the fluoride. The usual test given coating by the Arme Services is to rub the coating with standardized erasers, $^1/_4$ in. in diam eter, for 20 strokes across the same area of the lens at a pressure of 2.5 lb This amounts to a pressure of approximately 50 lb per sq in. If ther are no visible effects from this treatment, the element is considere acceptable. In addition to this test, Army and Navy requirement call for 24-hr immersion in salt water; a 95 F salt atmosphere for 2 hr, and a humidity test at 120 F at 95 per cent relative humidity for 2 hr. The magnesium fluoride can stand these and more severe tests

I have had many requests for instructions on how to clean coate lenses. It would seem from the Army-Navy specifications, that an treatment short of a wire brush would be all right. I would, however treat a coated lens as I would any other high-quality optical element I would recommend water or alcohol as a cleaning agent. A clea handkerchief is excellent for drying the lens. If the lens is covere with grit and dirt, try to remove this before real pressure with a hand kerchief is applied.

Up until 1943, every effort was exercised toward making coating more durable in all respects. This development program was carrie out so well that in October 1943, at an Army convention on coating it was decided that there was a need for a method to remove defectiv coatings. Several companies had accumulated moderately larg stocks of lenses which had defective coatings, and if a satisfactor means could be devised, these lenses could be salvaged. Many peopl worked on this problem and finally the boric-acid process was de veloped. This consisted in boiling the lenses in a concentrated solu tion of boric acid and salt water for 2 hr. The process was not re liable and was very hard on certain types of glass. Dense bariun crown glass and some flint glass were strongly attacked by the solu tion. The Navy Department then devised a much better method which could be used on all types of glass. This consisted in heatin the lenses in a concentrated solution of sulfuric acid and boric acid fo about one hour. This process was very successful but required cau tion and considerable time was lost in decoating.

Another process was developed recently at the Simpson Optica Company. This process consists in melting crystals of $KHSO_4$

potassium bisulfate, in a porcelain or enamel dish. The temperature should reach 250 C and care should be taken to prevent overheating and accidental addition of water. The lenses to be decoated are warmed and placed in the solution for approximately 2 min. The lenses are then removed and allowed to cool. The excess potassium bisulfate is then washed off in water. This process represents a considerable speed-up over the sulfuric-acid method and was found safe on all types of optical glass.

There are four main advantages in using a low-reflection coating:

(*1*) Elimination of reflection
(*2*) Increased transmission
(*3*) Greater contrast
(*4*) Better chemical stability

Elimination of surface reflections is mainly of interest to the photographer. Considerable difficulty is experienced in photographing directly toward a spot of light. A set of ghost images is usually created under these conditions. Coating the camera lens will minimize these ghost images to a point where they are hard to detect.

To demonstrate the increase in transmission obtained by coating, we coated all surfaces of one of our standard 5-in. anastigmat projection lenses and compared actual light measurements with an uncoated lens of the same design. The increase in transmission over the uncoated-lens system represents 33 per cent. This agrees very well with the theorectical reflection values.

Fig. 4 shows a graph giving the percentage reflection in relation to the index of the glass. From this we can determine the amount of light lost, provided we know approximately the index of refraction of this glass used in the projection lens. The first lens in this particular anastigmat has an index of about 1.62. According to the graph, we would expect 5.6 per cent reflection from the first surface. If we assume that 100 per cent of the light strikes the first surface, the transmission will be 94.4 per cent. The second surface will reduce this 94.4 per cent figure by 5.6 per cent which gives 89.1 per cent. The second lens in this system has an index of 1.65, which represents a reflection of 6 per cent per surface. If we continue the process of reducing the total transmission received by each surface, by the amount of loss, we arrive at a total transmission of 70.2 per cent. The low-reflection coatings are not 100 per cent perfect. On a glass that has an index of 1.62, we can reduce the reflection from 5.6 per cent to 0.9 per cent. This represents a gain of 4.7 per cent. On the other type of glass used in this projection lens, the gain is even greater, being 5.2

per cent per surface. Going through the projection lens, using the reflection values for coated glass, we obtained a transmission of 95 per cent. This means that the coated lens will transmit approximately 35 per cent more light than the uncoated lenses.

The increase in contrast of a coated lens has been investigated thoroughly by Tyler, Morris, and Jewett. They performed a series of photographic tests which showed that in photographing a subject

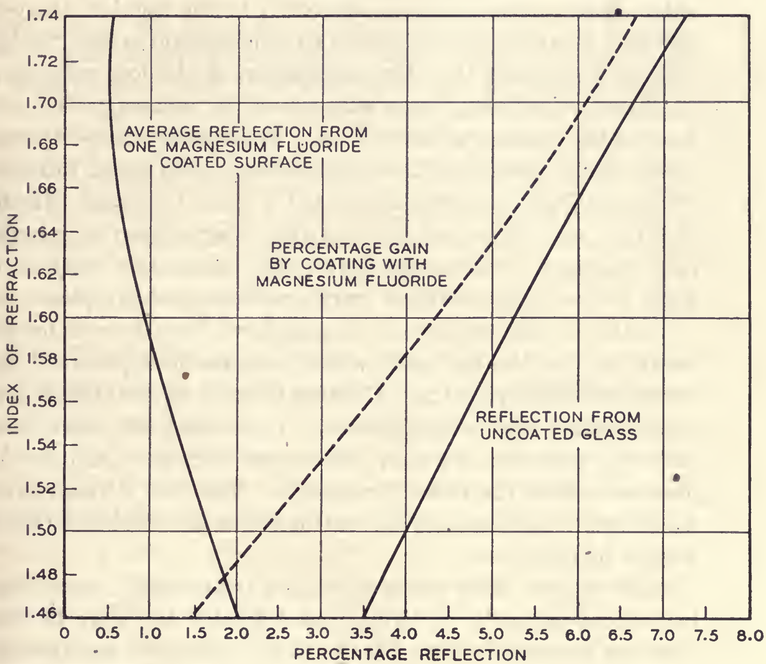

FIG. 4. White-light reflection values from one surface of glass and the percentage gained by coating.

which contains a large illuminated area such as the sky and darker foreground objects, a certain amount of the light from the sky is doubly reflected in the lens system and this light fogs over the darker areas of the picture. As expected, this contrast effect is much more noticeable when the light area of the picture is very bright.

A series of tests was made at Simpson Optical Company to determine whether a low-reflection film would protect glass from staining because of moisture. Two glasses were chosen which were known to

stain at a rapid rate. These were extra dense flint and barium c glasses. One side of each sample was coated with magnesium flu in the usual manner. The samples were placed in a salt-spray net in which we had replaced the salt solution with distilled w The samples were maintained at a temperature of 120 F for 1(The relative humidity inside the cabinet was 100 per cent and water accumulated on both sides of the samples during the test. examination the plates were found to be stained only on the unc side. The coated side was subjected to the regular Army-Nav spection procedure and found to pass inspection satisfactorily. this we concluded that the application of the low-reflection co to these less stable glasses will retard the staining effect at lea long as the coating will stand up. Tests were also performed o more stable glasses such as borosilicate crown glass, but no sta effect was found on either the coated or uncoated areas. In addit this test, several coated pieces of glass were subjected to hydrofl acid vapors. An exposure that would completely frost an unc glass showed only small pit marks in the coated samples.

While the low-reflection coatings have been known for alm years, all the developments which have made it practical have within the last five years. Coating is really in its infancy, and w expect many new developments. In the next ten years, coatin probably advance to a point where the index of refraction of th does not affect the reflection results. The first attempt at th made by Dr. Molten, but his coating which accomplishes this is st soft to be practical.

Although the color effect of coating is primarily caused by a tion of wavelengths of light, this difficulty too may be mini The lens designer is now able to use more air glass surfaces in or secure better image quality without the fear of poor contrast ar transmission.

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ECENT DEVELOPMENTS OF SUPER-HIGH-INTENSITY CARBON-ARC LAMPS*

M. A. HANKINS**

mmary.—During the evolution of cinematography there has been a constant nd for increased light from a single source. Early attempts to meet this demand made by improvements in lamp projection optics and by increasing both size and r input of the light source.[1] *In recent years a great deal of work has been done d increasing the intrinsic brilliancy of the high-intensity carbon-arc source. has resulted in a series of carbons known as super-high-intensity carbons.*[2,3] *paper will describe the requirements of the motion picture industry which ht about the production of these super-high-intensity carbons and will cover s of the development and design of carbon-arc lamps to burn them. The use of -high-intensity carbon-arc units in motion picture studios may properly be d into (a) Process background projection;*[4] *(b) Set lighting.*[1]

rocess Background Projection.—Process background projection neans whereby a stereopticon slide or a motion picture may be ected onto a translucent screen to form the background for a which has been constructed on the opposite side of the screen. tographing both the projected image and the set results in a com- te picture.[5] Inasmuch as the set on the camera side of the screen luminated for proper photographic exposure, it is quite evident the screen light must be of a much higher level than that in a ion picture theater.

hen this process first came into use, standard motion picture pro- on lamps were the only available equipment. In attempts to ease screen light the studios tried carbons from every available ce and were requesting carbons of higher current-carrying ca- ty than the design of the lamps permitted. At that time, car- s of higher current capacity were also of larger diameter and not ncreased intrinsic brilliancy. Because the optical systems in use e filled by the smaller diameter, lower current-capacity carbons, light gain was negligible and the increased heat often resulted in atisfactory operation.

Presented Oct. 25, 1946, at the SMPE Convention in Hollywood.
Mole-Richardson Co., Hollywood, Calif.

Higher levels of the proper intensity and quality of screen light called for co-ordinated effort between the studios and the various suppliers of equipment and materials. This demand resulted in activity on the part of the Research Council of the Academy of Motion Picture Arts and Sciences which led to a co-operative investigation of the entire subject by all of the studios and manufacturers involved.[6] Subsequent to the investigation by the Research Council Process Projection Committee, a report was issued covering recommendations on process projection equipment.[6]

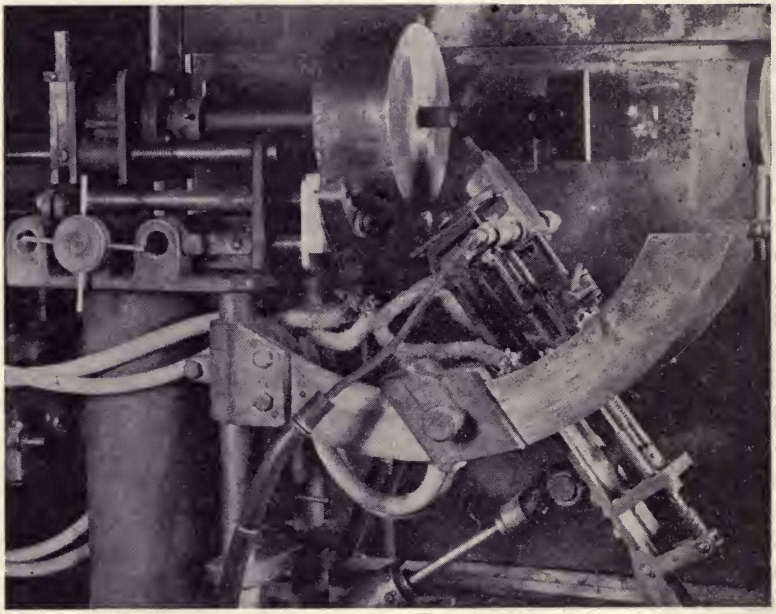

FIG. 1. Mole-Richardson test lamp. Close-up view through housing door opening showing details of the carbon-burning mechanism.

The Mole-Richardson Company agreed to design and build a process projection lamphouse which would meet the requirements outlined in the report. Inasmuch as a carbon-arc lamp is designed to feed and control carbons, this work was carried on in close co-operation with the National Carbon Company, Inc.

A laboratory test lamp was designed and several of them were built for use in Mole-Richardson Company's and the National Carbon Company's research and development laboratories. This unit (Fig. 1) will accommodate any size positive carbon from 11 to 18 mm in

diameter and may be adapted to burn other sizes. Separate motors control positive feed, negative feed, and positive rotation, so any desired variable of those three factors may be quickly obtained. The positive head may be adjusted for various lengths of carbon protrusion, and different types of air- and water-cooled positive carbon-current input contacts may be used. The negative carbon head is mounted on arms which allow it to be moved to carbon trim burning angles from coaxial alignment to 90 deg. Adjustments are provided for alignment of the carbons in both the horizontal and vertical directions. The negative head will accommodate various sizes of

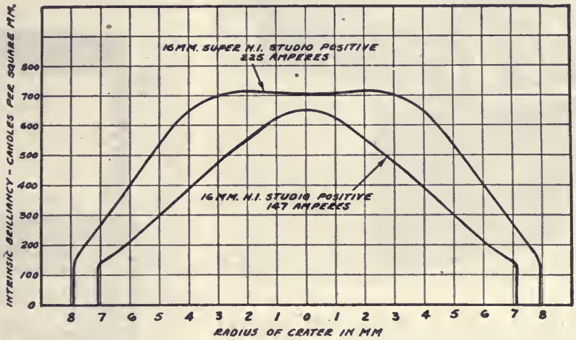

FIG. 2. Curves showing intrinsic brilliancy across the crater face of the "National" 16-mm super-high-intensity studio positive at 225 amp and the 16-mm high-intensity studio positive at 147 amp.

air-cooled negative carbons, and can also be equipped with water-cooled negative carbon-current input contacts. This lamp makes it possible to obtain any set of operating conditions which may be desired for experimental work under conditions of very close control.

As a result of a co-operative testing program, the National Carbon Company supplied a carbon trim consisting of a 16-mm × 22-in. super-high-intensity positive and a $^{17}/_{32}$- × 9-in. heavy-duty copper-coated negative to burn at a maximum current of 225 amp and 75 arc v (Fig. 2). This trim was chosen over others tested because of high intrinsic brilliancy, uniform distribution across the crater face, and steadiness of burning. For comparison, Fig. 2 also shows the standard 16-mm × 20-in. set-lighting carbon which is used in the *M-R* Type *170* lamp, and which delivers about one half the horizontal candle power.

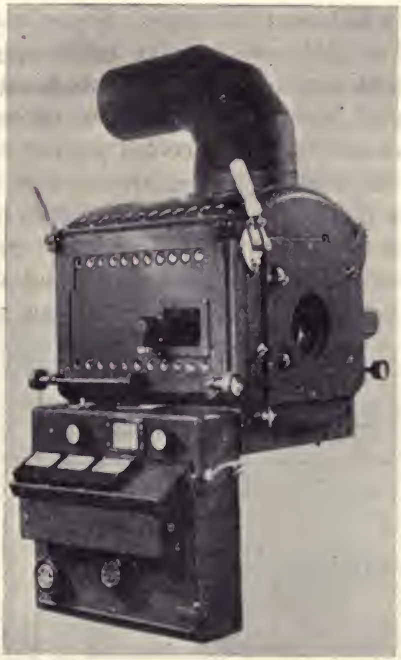

FIG. 3. *M.-R.* Type *250* process background projection lamp. Oblique view showing front and operator's sides. (The plate shown assembled to the front of lamphouse and the rheostat knob in lower left corner of control panel are parts of an associated process background projection equipment and are not furnished with the lamp.)

The Mole-Richardson Type *250* process projection lamp (Figs. 3 and 4), which burns this carbon trim, and its associated Type *251* grid (Fig. 5) have been designed and produced.

The major features of the lamp design are briefly described as follows:

(*1*) *General construction.*—The outline dimensions of the lamphouse are such that it can be conveniently assembled with associated process projec apparatus. The front por of the lamphouse is arrange accommodate the light-collec optical system together with supports and adjustments. L hinged access doors are provi in the lamphouse and con box for ease of maintena

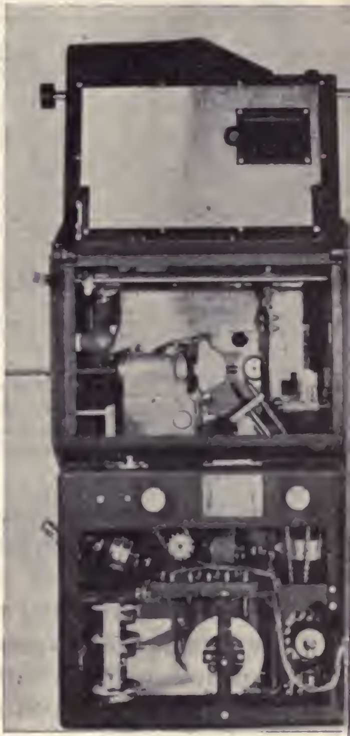

FIG. 4. *M.-R.* Type *250* pr background projection lamp. Vi operator's side with lamphouse and control-panel door open. bank of three rheostats shown i lower left corner of the control b part of an associated process b ground projection equipment a not furnished with the lamp.)

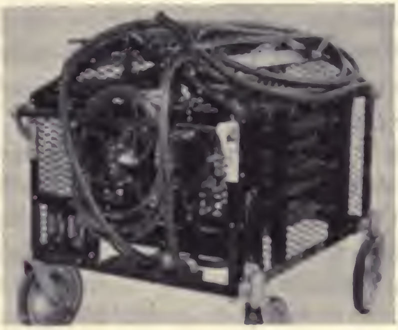

FIG. 5. *M.-R.* Type *251* grid for Type *250* process background projection lamp. Oblique view showing side and contactor-panel end.

ninum construction is used rever possible so that the ht is kept to a minimum. housing and its doors are of ble-walled construction with inner wall fabricated of as- os material. This type of truction results in a low smission of heat and sound the arc to the surround- area. Extra space is pro- d in the control box for nting instruments, switches, which are used with the asso- ed process projection apparatus. The control box and lamphouse be conveniently separated for ease of handling and shipment.

) *Positive carbon control.*—The positive carbon is rotated con- ously so that an even crater is maintained. A photronic-cell con- device causes the positive carbon to be fed forward as it burns so t the source of light is maintained within very close limits at the l point of the light-collecting optical system.

3) *Negative carbon control.*—The desired arc length is continuously closely maintained by a control circuit which positions the nega- carbon. When the arc switch is turned on, the negative carbon aused to be fed forward until it contacts the positive carbon, thus blishing the arc. The control mechanism then immediately acts the negative carbon to a position corresponding to the proper length, and maintains this arc length by continually feeding the bon forward as it burns.

4) *Cooling.*—The lamp is designed for satisfactory operation hout forced ventilation so that the objectionable noise of a ven- ting fan is absent. Openings in the lamphouse are provided for ural draft, and are arranged in such a manner that the resulting currents do not interfere with the stability of the arc.

The water-cooled positive head encloses carbon-contact brushes ich are cooled by their contact with a water-cooled casting. The ling water is circulated through the casting between the arc and brushes, so that the operating temperature of the brushes is con- erably lower than in conventional designs, and it is expected that le or no brush maintenance will be required.

A water-flow indicator is located on the rear of the lamphouse.

(5) *"Douser"*.—A "douser" in the form of a metallic plate is provided, which can be swung into position between the positive carbon and the light-collecting optical system. Its motion is mechanically interlocked with the motion of the operator's lamphouse access door. Closing or opening the door causes the douser to assume its position between the positive carbon and the optical system. Hence after the door is closed, the douser will protect the optical lens from heat shock and hot particles caused by striking of the arc. When the door is opened, the douser protects the lens from thermal shock which might result from cool air entering the housing from the outside. Manual positioning handles are located external to the lamphouse, so that the operator can "turn on" or "douse" the light through the optical system while the arc continues to burn.

(6) *Control panel*.—The control panel is equipped with instruments for indicating the line voltage, arc voltage, arc current, and length of unburned positive carbon. An arc-image screen provides the operator with a calibrated visual indication of the positions of the carbons. Knobs are provided for setting the arc-length regulating circuit, and for manual adustment of the positive and negative carbon positions. The lamp operation is entirely automatic, and is controlled by a small "off-on" toggle switch located on the control panel.

The *M-R* Type *251* grid which is supplied with the process projection lamp is designed specifically for the application. Adequately ventilated grid resistor units, which carry the arc current and produce the required voltage drop, are positioned in the center of the unit. Selector switches are mounted on a switch panel on one end of the unit, with connections made to various taps on the grid resistors. By manipulation of these switches, satisfactory arc operation can be attained with arc currents of 150, 180, 200, or 225 amp with any line voltage of 110 to 130 v in 5-v steps.

Two line contactors, a starting contactor, a time-delay relay, an auxiliary relay, and a selenium rectifier are mounted on the contactor panel on the end of the unit opposite to the switches. The coils of the main-line contactors are connected across the supply through the arc switch on the lamp-control panel, in series with the selenium rectifier. The rectifier prevents the main-line contactors from being energized if the supply to the system is not of the correct polarity.

A "starting resistance" is provided in the grid circuit to limit the

current on arc strike, and hence prevent the positive carbon crater from being damaged by the initial thermal shock. The starting resistance is automatically cut out of the circuit when negative carbon has retracted to its approximate operating position. This operation is accomplished by time-delay auxiliary relay and starting contactor.

Two bus bars are provided on the grid for connection to the direct-current supply. The grid is equipped with three cables for connections to the lamp, two heavy single-conductor cables for conducting the arc current, and one small three-conductor cable for the control circuits. The unit is mounted on sturdy rubber-tired casters of large diameter for portability.

The above-described process projection lamp and grid combination is representative of the present-day knowledge in the art of producing this particular type of projection equipment. However, research and developmental work is continually being conducted with efforts directed toward more and steadier light. Experiments are being made in connection with the possible use of a small-diameter water-cooled graphite negative carbon, which may produce a steadier light than is produced with the larger air-cooled negative carbons, and with no loss of light.

Tests are being made on a brushless water-cooled positive carbon contact unit without moving parts, which also promises to contribute toward the steadiness and increase in light output. Positive carbons are being considered which have brilliancies of as high as 1400 candle power per mm^2 and which may be operated up to 400 amp.

Set Lighting.—A careful study of cinematographic technique indicates that the present-day cinematographer often strives for an illusion of a "one-source" lighting, particularly in medium and long shots. While he must use a large number of units for balance, modelling, back light, and other effects which indicate his individuality, he works for an over-all result suggesting that the illumination is coming from one source of tremendous brilliancy such as is found in nature when the sun is just at the right position. This effect may only be obtained with a high-brilliancy source sufficiently small in area to cast well-defined shadows. The shadows cast by the other units are either covered by the main source or are eliminated with fill light, and while there may be a hundred lamps on the set, all noticeable shadows are cast by the main source, creating the illusion of a one-source lighting.

Previous to the advent of the super-high-intensity studio-type

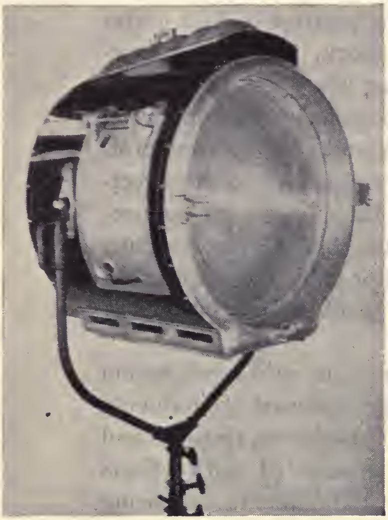

FIG. 6. *M.-R.* Type *450* super-high-intensity arc spot lamp. Oblique front view showing 24-in. diameter Fresnel lens and operator's access door.

carbon there were three general types of carbon arcs available for the motion picture studios:[7] (*1*) the low-intensity carbon arc where the principal light source is incandescent solid carbon at or near its sublimation temperature; (*2*) the flame arc where the light source is the entire arc stream made luminescent by the addition of flame materials; (*3*) the high-intensity carbon arc where, in addition to the light from the incandescent crater surface, there is a significant amount of light originating in the gaseous region immediately in front of the carbons as the result of the combination of high current density and an atmosphere rich in flame materials.

The low-intensity carbon arc has no present use in motion picture studio set lighting. The flame carbon arc is used in general lighting units for front light, fill light, and to illuminate backings. The high-intensity carbon arc is used in spotlamps.

The *M-R* Type *170*, operating at 140 to 150 amp and 64 to 67 arc v, has been the most popular carbon-arc lamp for use in creating a one-source lighting effect and for boosting daylight on exteriors.[1] However, the rather high light levels used on color pictures indicated a need

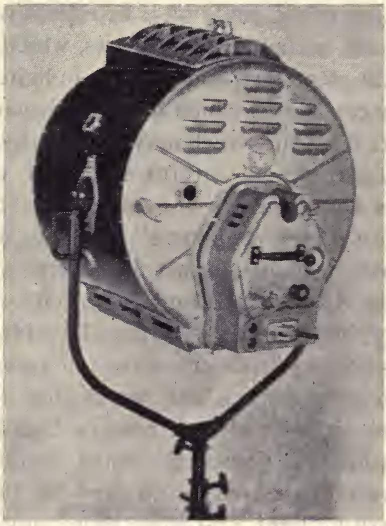

FIG. 7. *M.-R.* Type *450* super-high-intensity arc spot lamp. Oblique rear view showing operator's control panel on rear of control-mechanism housing.

for a unit of still greater volume and penetrating power.

A demand on the part of directors of cinematography for higher-powered sources resulted in some attempts by the studios to adapt the 16-mm × 22-in. super-high-intensity carbon to the *M-R* Type *170* lamp. The same troubles were encountered that had plagued the process projection departments when they attempted to increase current in standard projection lamps beyond the design characteristics.

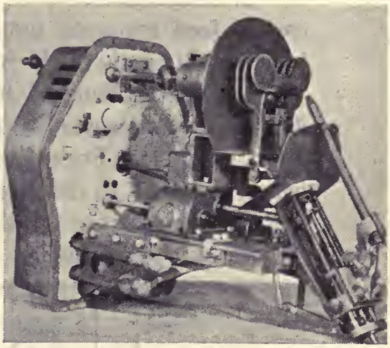

FIG. 8. Arc element and control mechanism subassembly for *M.-R.* Type *450* super-high-intensity arc spot lamp. Front oblique view showing unit removed from lamphouse.

When a carbon trim is burned at 225 amp in a Type *170* lamphouse, the interior of the unit becomes overheated, endangering the carbon-feed motor-current leads, and positive carbon brushes. A carbon trim which will burn steadily under conditions of proper lamphouse ventilation may become erratic and unsteady if the control mechanism is overheated. The gear ratios controlling the

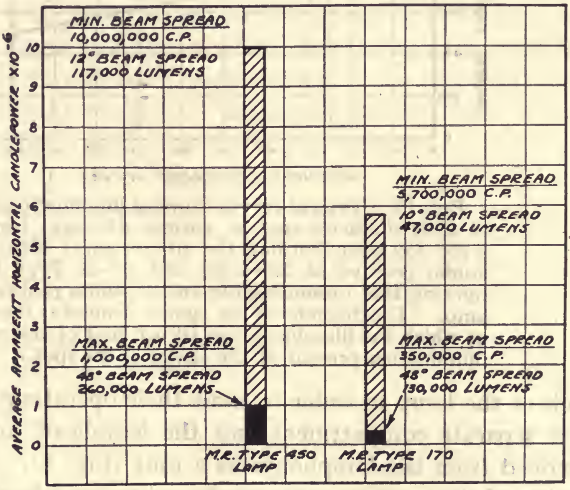

FIG. 9. Chart indicating relative illumination characteristics of *M.-R.* Type *450* lamp burning the 16-mm super-high-intensity studio positive at 225 amp and *M.-R.* Type *170* lamp burning the 16-mm high-intensity studio positive at 150 amp.

carbon-feed rates do not correspond to the burning rates or the burning-rate ratio of the higher-current carbons.

To meet the demand for a higher-powered unit, the *M-R* Type *450* lamp was designed (Figs. 6 and 7). This unit is equipped with a 24-in. diameter Fresnel-type condenser lens. The drum is of sufficient diameter to ensure proper ventilation, the unit is wired for the increased current, and the feed motor, feed-motor rheostat, arc switch, and pin-plugs are located in a separate compartment on the

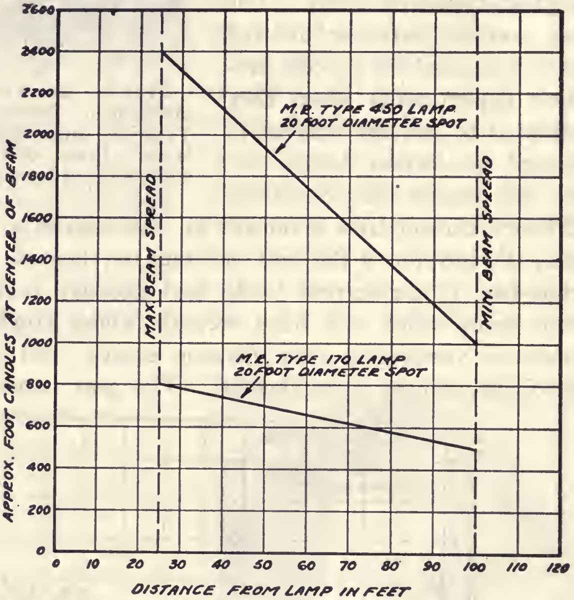

FIG. 10. Typical curves showing illumination at center of 20-ft diameter spot at various distances from *M.-R.* Type *450* lamp burning the 16-mm super high-intensity studio positive at 225 amp and *M.-R.* Type *170* lamp burning the 16-mm high-intensity studio positive at 150 amp. (The diameter of the spot is defined as the diameter at which the illumination is 10 per cent of the maximum illumination present at the center of the spot.)

back of the lamp in order to limit their operating temperature rise. This separate compartment and the lamphead mechanism can be removed from the lamphouse as a unit (Fig. 8). Hence, a subassembly of the working parts can be set up on a bench for convenient servicing. The carbon trim consists of a 16-mm × 22-in. super-high-intensity MP studio positive and a $^{17}/_{32}$- × 9-in. *HD* cored Orotip negative burning at 225 amp and 75 arc v.

The chart in Fig. 9 gives a comparison of the illumination characteristics of the Type *450* and Type *170* lamps. In the maximum flood condition, the amount of luminous flux in the Type *450* beam is approximately double the amount in the Type *170* beam, and the apparent horizontal beam candle power is almost tripled. In the minimum spot position, both the flux and candle-power values for the Type *450* lamp are approximately twice those for the Type *170*.

A comparison of the illumination of a 20-ft diameter spot as produced by the Type *450* and Type *170* lamps is shown in Fig. 10. It is apparent that the Type *450* lamp represents a considerable increase in the "penetrating power" of lamps for studio-set lighting.

Another unit in the advanced stages of design is a super-high-intensity spot projector which will be similar to the Type *450*, but which will be equipped with an integral optical system for throwing a well-defined and closely controlled spot for use in follow shots such as would be made in a skating picture.

Experience gained in the manufacture of specialized searchlight equipment during the war will be of considerable value in increasing further the light output of motion picture studio lamps using super-high-intensity carbons.

We wish to acknowledge the co-operation of the Transparency Department and Mr. Farciot Edouart of Paramount Studios in the design and production of the special process lamp; the splendid cooperation of numerous cinematographers and the Electrical Department members in the work which was done on the "Brute" Type *450* lamp; and the National Carbon Company, Inc.

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A NEWLY DEVELOPED LIGHT MODULATOR FOR SOUND RECORDING*

G. L. DIMMICK**

Summary.—*A new light modulator, recently developed, has very low distorti and greatly improved performance characteristics. It is of the magnetic type and mechanically and optically interchangeable with the present RCA sound-recordi galvanometers. The power required for 100 per cent modulation is 1.25 w. D tortion characteristics, frequency-response curves, and impedance data are shou The effect of bias current upon the performance characteristics is also given.*

A galvanometer of the magnetic type was first used with the RC studio recording optical system in 1932. Although the basic design this galvanometer has remained the same since that time, its perforn ance and reliability have been considerably improved as the resu of changes in the mechanical, magnetic, and electrical component For many years the most serious obstacle to further reduction in di tortion and hysteresis was the limit on galvanometer sensitivity s by the maximum power available from recording amplifiers already use. This obstacle was eliminated when the decision was made to d velop a new 10-w, high-quality recording amplifier, and to develop new galvanometer to operate with this amplifier. The characteri tics of the new amplifier are described in a separate paper written b Kurt Singer. It is the purpose of the present paper to describe th changes which have been made in the recording galvanometer and show how these changes have reduced distortion and greatly inprove the performance characteristics.

The types of distortion which are most detrimental to the operatic of the recording galvanometer are:

(*1*) Odd harmonic distortion of the wave shape
(*2*) Even harmonic distortion of the wave shape
(*3*) Hysteresis
(*4*) Lack of linearity between current and deflection

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* Presented Oct. 25, 1946, at the SMPE Convention in Hollywood.
** RCA Victor Division, Radio Corporation of America, Camden, N. J.

ffect of d-c bias current upon a-c modulation characteristics istortion of the frequency characteristic.
armonic distortion results almost entirely from magnetic satu- the armature *A* shown in Fig. 1. This can best be reduced ining an armature with a reserve of flux-carrying capacity han that required to produce the normal 100 per cent deflec- the mirror. Even-harmonic distortion is caused almost en- a dissymetry in the two magnetic paths, shown by the dotted Fig. 1. This may be caused by the armature being off center, y be caused by the pole pieces *B* of Fig. 1 not being mechani- magnetically identical. The distortions listed above as (*5*) are caused largely by the inherent properties of magnetic

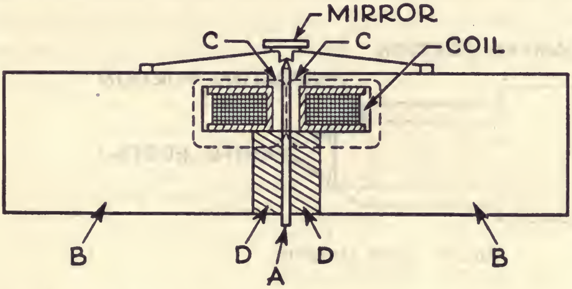


FIG. 1. Top view of galvanometer.

s. After these types of distortion are minimized by the use of magnetic materials, properly annealed, a further reduction is by increasing the length of the gaps *C* and *D* (Fig. 1), thereby the iron path with more air. Distortion of the frequency ristic may result from having the wrong amount of damping echanical vibrating system, or it may be caused by a variation optimum ratio of inductance to resistance in the electrical

ntioned above, one way of reducing the undesirable effects of o make the magnetic circuit include more air and less iron. ew galvanometer this was accomplished by increasing the gaps *C* (Fig. 1) from their former value of 5 mils each to a 10 mils each. The thickness of each nonmagnetic spacer *D* ck of the pole pieces was also increased from the former value s to a value of 50 mils. Taking into account the larger area ack gaps, the above change resulted in a 3-to-1 increase in

the air reluctance included in the magnetic circuit. Even with the same armature and pole pieces used in former designs, the above change would have improved the distortion of the types listed above as (*3*), (*4*), and (*5*). We needed, however, to reduce the odd-harmonic distortion as well, and this required an armature that had a greater flux-carrying capacity. This was accomplished in the new galvanometer by increasing the width of the vibrating section of the armature by 50 per cent. The dotted lines of Fig. 2 show the former width, while the full lines show the new armature shape. The wider section is maintained out to the point at which the armature enters the front air gaps. From here it tapers down to its former width at the base of the knife edges. The thickness of the new armature is the same as in the former design, and the armature material is an iron-nickel alloy.

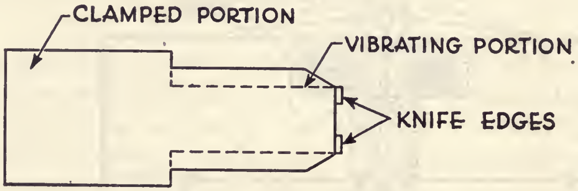


FIG. 2. New armature.

This change in armature dimensions allows 50 per cent more flux to enter the gaps before saturation is reached. But the change also increases the stiffness of the armature by nearly 50 per cent. The increased force necessary to overcome this stiffness is obtained by making the pole pieces of an iron-cobalt alloy. The use of this alloy allows the permanent polarizing flux density to be raised almost 50 per cent above that which is obtainable with the present pole pieces. In a balanced armature arrangement like that of Fig. 1, it can be shown that the force exerted on the armature is directly proportional to the total flux entering the air gaps (from the armature) and to the permanent polarizing flux density in the air gaps.

With the new pole pieces, the amount of armature flux required to produce 100 per cent deflection of the wider armature is equal to that which was formerly required to produce the same deflection of the narrow armature. The wider armature and new pole pieces therefore give us the reserve flux-carrying capacity necessary to reduce materially the amount of odd-harmonic distortion.

In a magnetic circuit containing both air and iron, the effective

value of hysteresis is reduced as the ratio of air to iron is increased. In the new galvanometer the ratio of air to iron included in the magnetic circuit has been increased 3 to 1, and the effective hystersis is therefore substantially less than in the former design. The most important effect of this is that when the new galvanometer is used on a recording optical system, the light beam returns to its zero position (or its biased position) with a greater degree of precision.

As mentioned above, the increase in gap lengths resulted in almost a 3-to-1 increase in the reluctance of the magnetic path. This had to be offset by an equivalent increase in ampere turns in the coil. If the coil design were left unchanged and the current increased 3 to 1, the necessary flux could be obtained, but the heat developed in the coil would go up nine times, and this would be prohibitive. To get around this difficulty, the amount of copper in the modulation coil was increased about 5 to 1, thus greatly increasing the coil

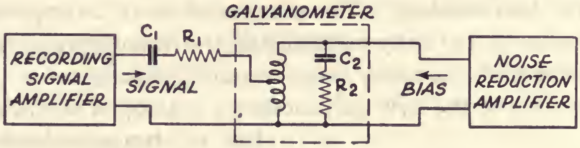


FIG. 3. Circuit of new galvanometer.

efficiency. Increasing the amount of copper in the coil also increases the ratio of inductance to resistance, and it is, therefore, necessary to add an appropriate amount of series resistance in order to obtain the required frequency response. This series resistance may be located in the amplifier, thus allowing most of the heat to be dissipated outside the galvanometer.

All galvanometers of the present design have had two separate coils, a modulation coil and a bias coil. In the new model, it was decided to make a single coil serve for both modulation and bias currents. This does not interfere with the normal operation of the bias-type noise-reduction system because the modulation current is maximum when the bias current is minimum, and vice versa.

The coil for the new model galvanometer was made by winding enamel wire on a bakelite-coil form. A tap was taken off for the portion of the coil used for modulation, while the whole coil is used for bias. The determining factor in deciding the number of turns on the modulation portion of the coil was the output impedance of the new

recording amplifier. The modulation portion of the coil was made to have an impedance which would assure galvanometer operation directly out of the amplifier without the customary matching transformer. The whole coil was wound with enough turns to provide a bias sensitivity of 30 ma. This makes it possible to use the new galvanometer with present noise-reduction amplifiers, modified for bias-type noise reduction. It also works equally well when using the shutter-type of noise-reduction system.

Fig. 3 shows how the new galvanometer is connected into the circuit of the recording amplifier and the noise-reduction amplifier. Resistor R_1 is the series resistance referred to above and at present is located in the amplifier. The capacitor C_1 is for the purpose of blocking the passage of bias current into the recording amplifier. It has a value of 10 μf which results in an attenuation in the frequency response of only 0.5 db at 60 cycles. The capacitor C_2 and the resistor R_2 are located inside the galvanometer case, and the series network is connected across the bias winding. The purpose of this is to improve the frequency response by partially neutralizing the inductance of the modulation coil in the mid-frequency range around 3000 cps.

The vibrating system of the new galvanometer is damped by means of a line of tungsten-loaded neoprene, one end of which is fastened to an extension of the mirror plate, and the other end is left free. As the mirror is rocked, the end of the line is deflected in torsion, and at high frequencies (5000 to 10,000 cycles) a relatively large amount of energy is radiated down the line. The line is long enough and its attenuation high enough for this energy to be practically all dissipated before it gets back to the mirror plate after being reflected at the open end of the line. Fig. 4 shows the new damping line in relation to the other parts of the

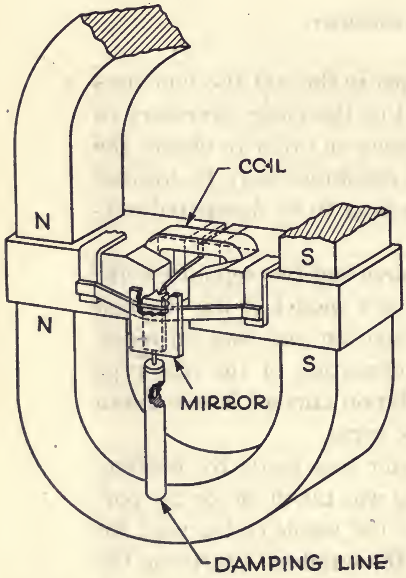


FIG. 4. Galvanometer with damping line.

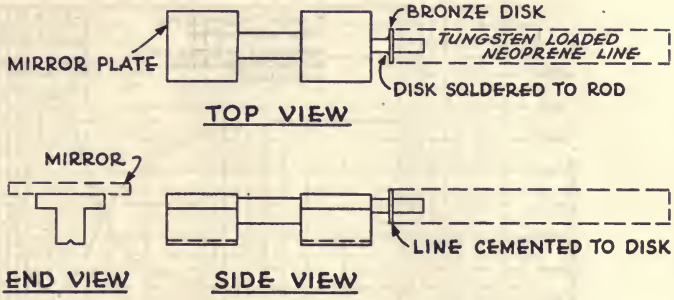


FIG. 5. Details of mirror plate and damping line.

galvanometer, and Fig. 5 is an enlarged view of the mirror plate showing the method of fastening the line. The line is made of neoprene which is loaded with fine tungsten powder. Neoprene is used in place of rubber because it has a higher coefficient of damping and is less affected by temperature. Tungsten powder is used because it is very heavy and is relatively inert.

The new line-type damper has many advantages over the antiresonant type of damper which has been in use on RCA recording galvanometers for many years. The line damper is easier to make because it is not tuned and is not critical as to length or size. It is easier and less expensive to service because it is a part of the bridge assembly and can be removed or replaced without affecting the armature and pole-piece assembly. It is relatively unaffected by temperature within the

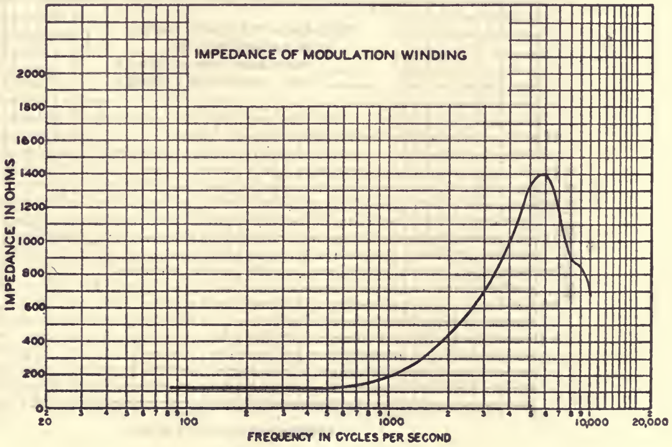


FIG. 6.

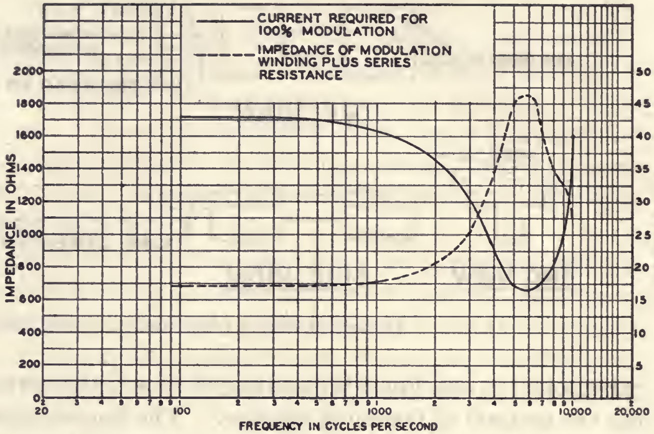


FIG. 7.

normal operating range. The damping is linear with amplitude, thus making it possible to obtain practically the same frequency response at all input levels.

Fig. 6 shows how the impedance of the modulation winding varies with frequency. This curve was taken at the terminals of the galvanometer. The dotted curve in Fig. 7 shows how the total impedance (galvanometer plus series resistor) varies with frequency. The full line of Fig. 7 shows the current required for 100 per cent modulation at different frequencies. The product of the two curves in Fig. 7

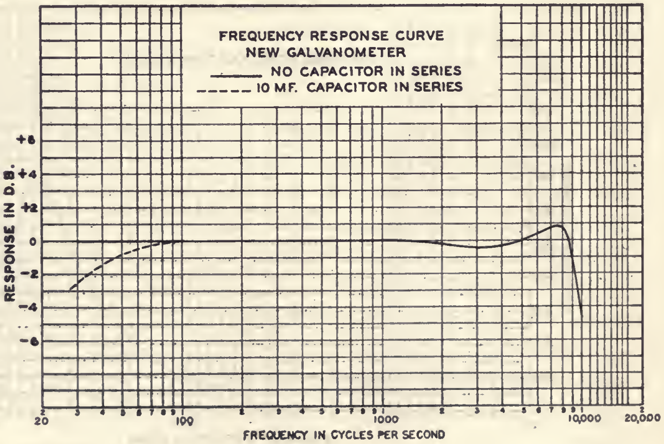


FIG. 8.

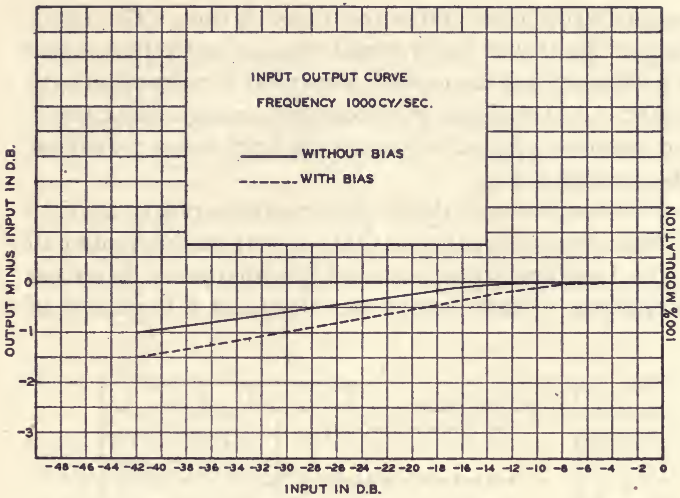


FIG. 9.

gives the voltage required to produce 100 per cent modulation at different frequencies. By taking the reciprocal of the above products and expressing them in decibels we obtain the frequency response curve of the new galvanometer shown in Fig. 8. The dotted line in this figure shows the effect of a 10-μf capacitor in series with the modulation winding.

Fig. 9 shows input-output curves taken at a frequency of 1000 cycles

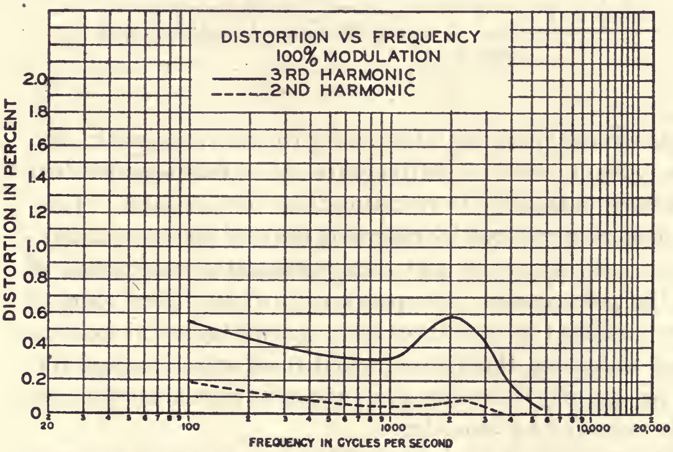


FIG. 10.

ıd over a range of 40 db below 100 per cent modulation. The curve arked "with bias" was taken under conditions similar to those which ɔuld exist if a noise-reduction amplifier were used in connection with e galvanometer. As the signal was decreased, enough bias current as applied to keep one edge of the recording light beam coincident th one of the limiting lines.

Fig. 10 shows how second- and third-harmonic distortion varies with equency. These curves are taken at 100 per cent modulation at all equencies. Fig. 11 shows how second- and third-harmonic distortion ıries with amplitude. These curves were taken at a frequency of 00 cps.

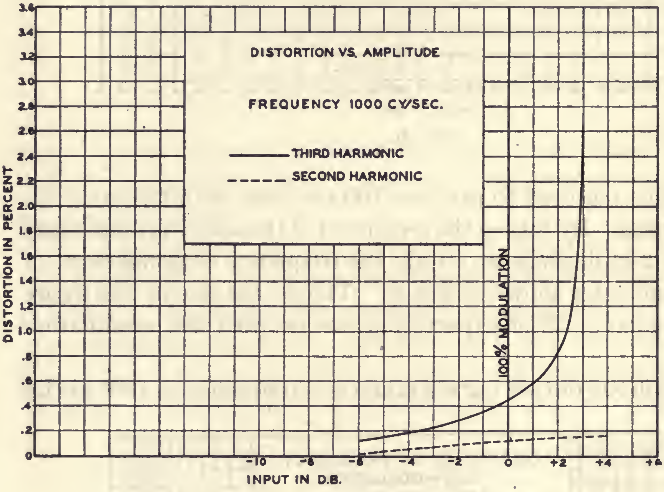


Fig. 11.

In addition to having lower distortion and better operating character-ːics, the new galvanometer is relatively free from temperature drift ıd from variations in sensitivity resulting from temperature. Tem-erature drift has been reduced by clamping the pole pieces on a stain-ss-steel support having nearly the same temperature coefficient of ːpansion as the pole pieces. Temperature drift has been reduced ill further by cutting the armatures from a solid bar of nickel-iron loy instead of obtaining them from rolled-sheet stock as was for-erly done. Apparently the rolling process results in strains which are ɔt completely removed by annealing.

The new galvanometer is equipped with a pair of alnico magnets

which have been fully charged and then demagnetized to about half their maximum strength. When used in this way, these magnets are extremely stable. This is important from a service standpoint, since the magnets may be removed from the pole pieces and later replaced without changing the air-gap flux density from the optimum value set at the factory. These magnets are also relatively unaffected by temperature, vibration, and stray fields.

The galvanometer is mounted in a cylindrical aluminum case and is mechanically and optically interchangeable with the present RCA recording galvanometers. The capacitor which was formerly mounted on the back of the case has now been mounted inside the case. The glass window in front of the mirror has been made larger in diameter so as to allow light to enter and leave the galvanometer at a greater angle to the normal. The power required for 100 per cent modulation of the new galvanometer is 1.25 w.

Acknowledgment is due J. L. Pettus and H. E. Haynes for important work in connection with the development of the new recording galvanometer.

THE PHYSICAL PROPERTIES AND THE PRACTICAL APPLICATION OF THE ZOOMAR LENS*

FRANK G. BACK**

Summary.—*The "Zoomar" lens is a varifocal objective for motion picture cameras which achieves the change of focus by the linear movement of a single barrel. The new feature of this lens consists of the principle of changing the focal length of the system by one group of lens components without consideration of the displacement of the image plane, while a second lens component, rigidly coupled to the first by the common barrel, compensates for this displacement.*

The "Zoomar" varifocal objective has been developed as a tool for making "zoom" shots in places and on occasions where the usual methods of wheeling the camera toward or away from the object are either impossible or uneconomical. On the screen it seems as if the camera were moving toward the object—in reality the camera, as well as the object, remains stationary. The apparent movement is

* Presented Oct. 25, 1946, at the SMPE Convention in Hollywood.

** Research and Development Laboratory, 381 Fourth Ave., New York.

produced optically. During the zoom the image size varies but is always in focus. The light transmission remains constant over the entire zoom.

The basic differences between the Zoomar lens and other varifocal objectives has been discussed in a previous paper.[1]

Fig. 1 shows the Zoomar lens mounted on a Ciné Kodak Special.

Fig. 2 shows a cross section of the lens. When the zoom lever is in the forward position the Zoomar is a wide-angle lens with an equivalent focal length of 17 mm. As the zoom lever is moved back the equivalent focal length of the lens increases to 53 mm, and in the rear position it has the characteristics of a telephoto lens.

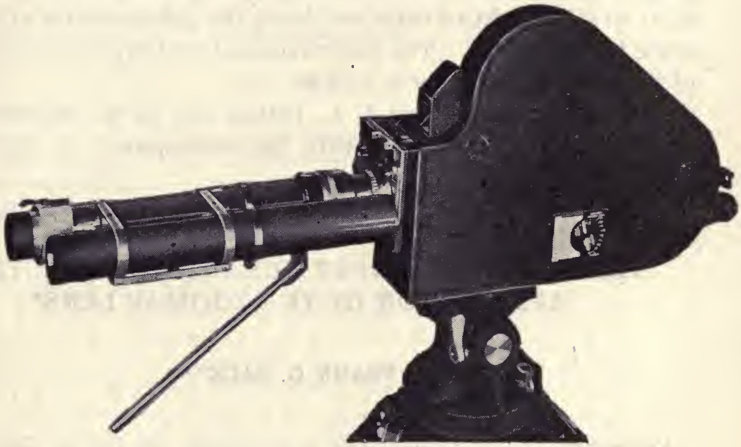


Fig. 1. Zoomar mounted on Ciné Kodak Special.

The construction of the lens is mechanically simple with no gears or cams and only one movable barrel. The barrel carries five lenses which move with it, varying the size of the image and compensating for distortion and aberrations. The four lenses at the front end of the movable barrel produce the variation in the image size.

The rear lens of the movable barrel keeps the image in focus during the zoom. The rest of the lenses are stationary and fixed to the Zoomar body.

The principle on which the function of these four lenses is based, was first used in a varifocal viewfinder developed for the combat cameras of the Armed Services.[2]

FIG. 2A. Wide-angle position.

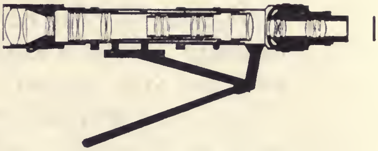


FIG. 2B. Intermediate position.

FIG. 2C. Telephoto position.

Changing the front lens increases the range of Zoomar from 35 to 106 mm equivalent focal length, but the image remains in sharp focus and the light transmission is constant.

Naturally, the complicated optical system of the Zoomar was basically afflicted with many aberrations. Correction of these

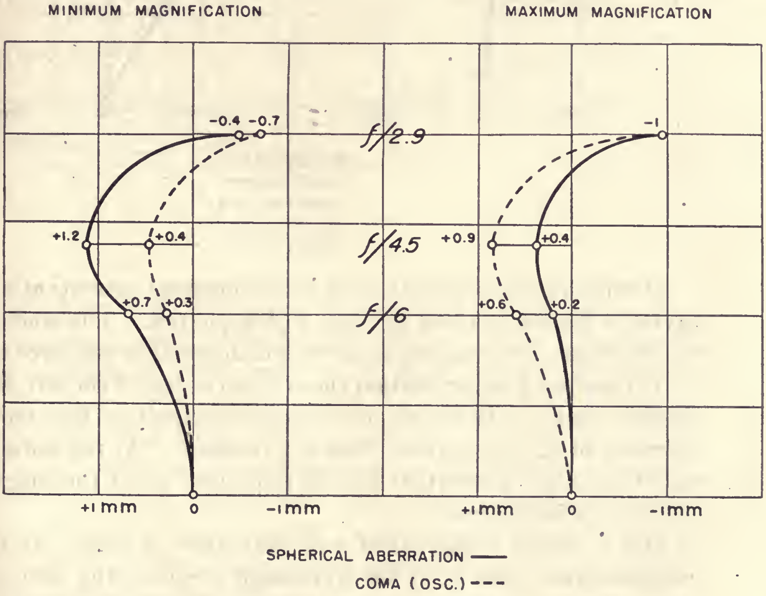


FIG. 3.

aberrations was one of the major tasks in designing the Zoo
Ordinary correction methods of optical design broke down and
ways had to be devised.

Fig. 3 is a graphical presentation of the spherical aberration
coma at maximum and minimum magnification. The solid
represents the spherical aberration; the dotted line shows c
expressed, as is customary, offense against the sine condition.
sine condition is fulfilled when the spherical and coma curves coin

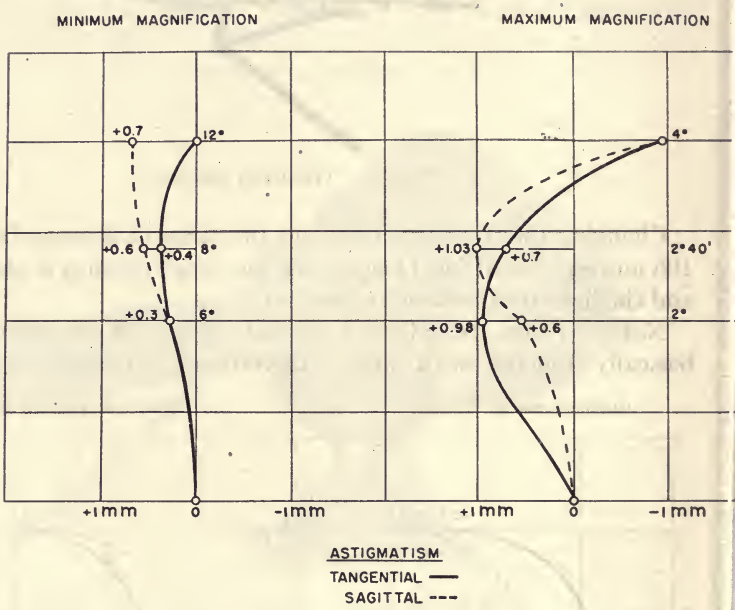


FIG. 4.

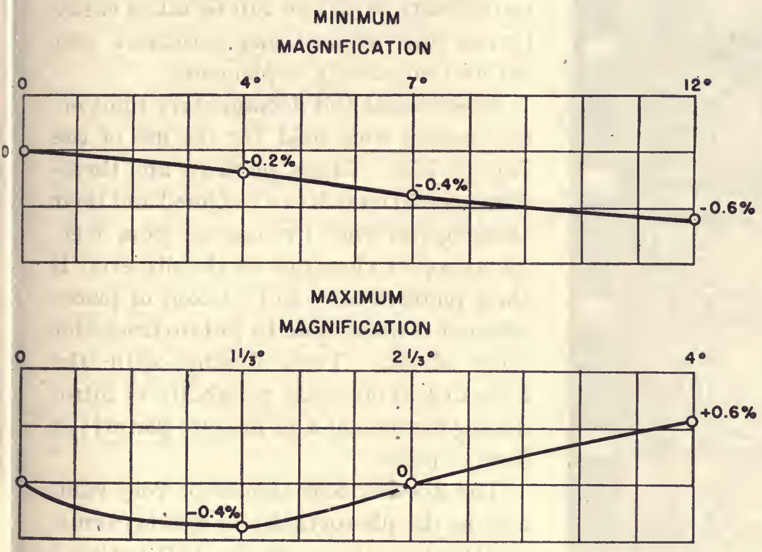
At minimum magnification the zonal spherical aberration is grea
giving a certain over-all softness to the picture. The sine curv
to the right of the spherical curve which signifies negative coma

At maximum magnification the sine curve lies to the left, indic
positive coma. Therefore, the absolute amount of this most o
tionable of all aberrations does not increase. At the same tim
zonal spherical aberration has its minimum when the magnific
reaches its maximum.

Fig. 4 shows astigmatism and curvature of field. At mini
magnification, that is, at the wide-angle position, the field is fla
the astigmatic difference is negligible. At maximum magnific

ve have a slightly curved field; and, though astigmatic correction is chieved at the intersection of the two curves, we still have astigmatic ifferences above and below the node.

If we compare astigmatism and spherical aberration we see that at he wide-angle position the correction of zonal spherical aberration ad to be sacrificed in favor of astigmatic correction, giving a flat, if omewhat soft, image. At maximum magnification where the smaller ngular extent of the field renders astigmatism relatively harmless, the tress has been put on spherical correction.



DISTORTION

FIG. 5.

Fig. 5 shows the distortion of the system which is negligible. At the wide-angle position the trend is toward a barrel. For maxi- um magnification the outer part of the field shows a pincushion, hile the inner part still produces barrel distortion. The amount of stortion shown in this diagram is only a fraction of 1 per cent. The aphical presentation of lens aberrations has been greatly exagger- ed in order to show the way in which they change during the zoom. As it is impossible to enumerate all the different applications of the oomar lens to practical motion picture work, we can list only a few the more striking possibilities.

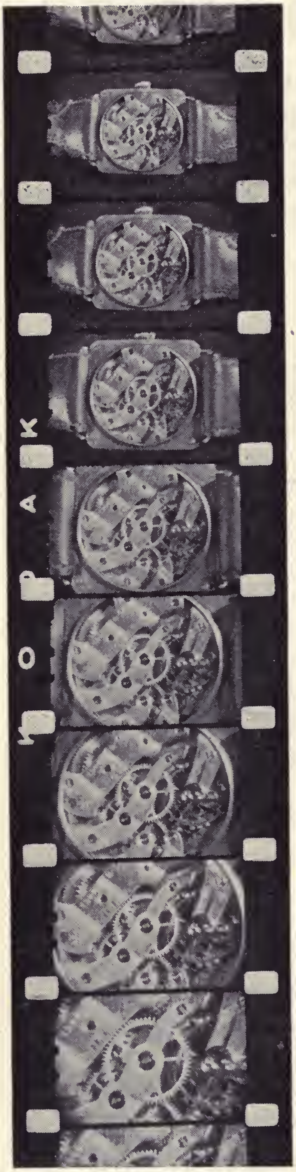


FIG. 6. Ultra close-up of wrist watch.

A combination of tilting, panning, and zooming is very difficult to achieve by conventional means, requiring perfect timing and the co-ordination of a highly skilled team of trained cameramen and technicians. Such a shot can be taken only in studios where cranes or booms with the necessary tracks, *etc.*, are available. With the Zoomar, such a combination shot offers no difficulty at all and can be taken easily by one man without any assistance and without any costly implements.

Educational and documentary films offer another wide field for the use of the Zoomar lens. Maps, pictures, and three-dimensional models can be filmed and their showing enlivened by zooming from over-all views to close-ups of details even if these pictures have to be taken in places where it is impossible to put up tracks for dolly shots. Thus filming with the Zoomar lens offers the possibility of introducing movement and life into pictures of dead objects.

The Zoomar lens should be very valuable in the photography of sports events. On the race tracks, in the ball park, on the gridiron, to name only a few examples, it would be very desirable if the cameraman could leave his box and shoot an interesting detail at close range. For obvious reasons, this is impossible. If he changes to a telephoto lens the exciting event is over when he is through with focusing his new lens, setting his diaphragm, *etc.* The abrupt change of focal length together with the above-mentioned time lapse breaks up the continuity and makes it difficult for the spectator to understand the action on

the screen. With the Zoomar lens he can roam at will over the field and follow the horses or players wherever they go in one continuous, smooth shot and at the same time show all the details which contribute to the excitement of the event.

Industrial shots can be enlivened and detail of machinery can be clearly shown with the Zoomar. Here again, the smooth and gradual transition from over-all shots to close-ups saves a lot of explanations which are necessary when long shots and detailed close-ups follow each other abruptly as has been customary.

The same is true in the photography of commercial articles like costume jewelry. The zoom can be used to call attention of prospective buyers to details of workmanship and so on.

In medical pictures, the use of zoom shots is nearly unlimited, especially in the field of surgery where close-ups of details are of the highest importance. At the same time, long shots have to be inserted to facilitate orientation of the students who are going to see that picture.

Even ultra-close-ups, like the inside of a wristwatch, can be produced with a great amount of perfection (Fig. 6).

It is no exaggeration if we say that the close-up, this powerful means of expression given to the motion picture art by D. W. Griffith, has really come into its own by the introduction of the zoom shot. The Zoomar lens eliminates the difficulties which up to now have complicated the use of this technique.

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SPECIAL CAMERAS AND FLASH LAMPS FOR HIGH-SPEEI UNDERWATER PHOTOGRAPHY*

ROBERT T. KNAPP**

Summary.—*The equipment described was developed for analyzing underwat motion of solid bodies. The experiments demanded a high rate of picture takir and that the subject studied should be in the field of at least two cameras at all time Edgerton-type flash lamps instead of shutter mechanisms were adapted, an endle film belt giving a one-second exposure was developed, and a film speed of approx mately 35 ft per sec used.*

The Problem.—For the past few years much of the work of th Hydrodynamics Laboratory of the California Institute of Tech nology has been in connection with projects for Division 6 of th National Defense Research Council and for the Bureau of Ordnanc of the U. S. Navy. One of these projects required for its study th development of methods for making detailed measurements of th path and the orientation of a rapidly moving underwater body Consideration of the project showed that the work could be carrie out in a horizontal, cylindrical tank about 30 ft long, with a depth o water of approximately 10 ft with a few feet of air space above th water surface. The desired range of experimental conditions im posed the necessity of varying the pressure from a positive value o two or three atmospheres down to a vacuum of a small fraction of a atmosphere. This means that the tank had to be a closed pressur vessel and that very large windows would be both expensive an hazardous. In spite of the difficulties involved, detailed study of th problem indicated that the photographic method of measuring th performance of the body was the most promising.

Careful analysis of the probable experimental needs of the progran indicated that to secure the desired information, measuring point would have to be obtained at a maximum rate of from 1000 to 300

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* Presented Oct. 22, 1946, at the SMPE Convention in Hollywood.

** Hydrodynamics Laboratory, California Institute of Technology, Pasadena Calif.

per sec, depending upon the speed of the underwater body that was being observed. However, since the size of the tank limits the length of the path without regard to speed, the maximum number of points required for any one set of measurements was calculated to be about 3000. If these measurements were to be obtained by the use of motion pictures, these requirements meant that camera equipment would have to be developed that could take up to 3000 frames at a speed of from 1000 to 3000 per sec. Furthermore, an analysis of the required accuracy of measurements showed that very little distortion could be tolerated. This indicated that the rotating prism-type of high-speed camera would not be suitable. It was finally decided that the best possibilities appeared to lie in the direction of a camera using a constantly moving film strip with no shutter mechanism, operating in conjunction with a battery of high-speed flash lamps which could act both as a source of illumination and as a shutter.

The underwater bodies to be studied were of a type which would enter the water from the air at one end of the tank with a relatively high velocity. From the point of entrance on, they would be free bodies and thus could move to any point in the tank, depending on the resultant forces that acted upon them. This meant that the photographic measuring technique had to be able to determine the position of the body in space. In other words, it would be necessary to obtain the horizontal and vertical co-ordinates of the body in a plane normal to the axis of the recording camera, but it also would be necessary to obtain the horizontal distance of the body from the camera. The best way to do this appeared to be by the use of the stereoscopic effect, which meant that for each point recorded, the body would have to be photographed by at least two cameras.

To ensure this condition, a design specification was established that in the nominal plane of focus, the set of cameras should be so spaced that their fields of view would have a 60 per cent overlap. As a result of this, together with the other experimental requirements, the recording equipment developed into a bank of five cameras, spaced at $4^1/_2$-ft centers and operated from a common drive shaft. This gives a coverage over the entire experimental region of the tank. The central 20 ft of the 30-ft tank has a two-camera coverage over the effective width and depth, with single-camera coverage on the two 5-ft end sections. Fig. 1 (*a*) and (*b*) shows the diagrammatic arrangement of the cameras in the tank with their overlapping fields of view.

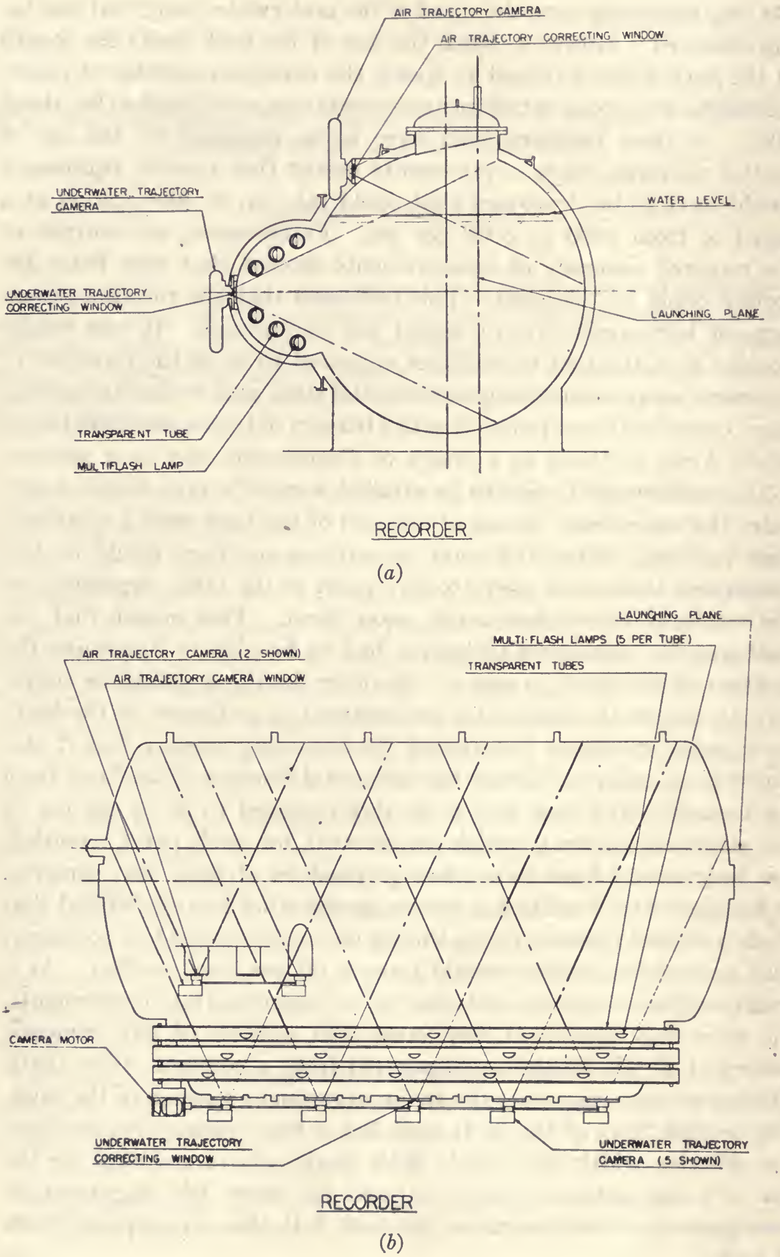

FIG. 1. Diagrams showing arrangement of cameras and their overlapping fields of view.

Detailed Requirements of Cameras and Light Sources.—In the design and development of a camera system of the type just outlined, it is necessary always to bear in mind the extreme importance of the relationship between the camera and the lights because the lights function as an essential part of the camera, since they replace the normal shutter mechanism. In fact, the characteristics of the flash lamps control much of the design of the camera itself. Therefore, these relationships will be discussed first in analyzing the detailed requirements of the over-all design.

The most important characteristic of the flash lamp itself is probably the effective duration of the flash. The minimum available flash duration controls the maximum usable film speed. It must be remembered that in this type of camera the film moves constantly. Therefore, the flash duration of the lamp must be short enough to "stop" the motion of the film; otherwise, the recorded image will be blurred. One reasonable criterion of the maximum usable film speed is that the allowable amount of motion during one flash should not be greater than the circle of confusion of the lens of the camera. For most applications, this is a much more severe requirement than the one derived from a consideration of the possible image blur caused by the movement of the object being photographed.

This difference can be seen easily by considering a set of typical conditions for the installation under discussion. The maximum speed anticipated for the body to be photographed is in the neighborhood of 200 to 300 ft per sec. Its average distance from the camera will be about 100 to 150 focal lengths. Thus the average speed of the image in the focal plane of the camera will be only about $2^1/_2$ ft per sec. Therefore, a film speed of $2^1/_2$ ft per sec would cause the same amount of blur for a given flash duration as would the movement of the object itself. It will be remembered, however, that experimental requirements call for a camera which can take from 1000 to 3000 frames per sec. Obviously, it would be impossible to take 3000 pictures per sec on a film having a speed of $2^1/_2$ ft per sec since the frame height would be less than $^1/_{100}$ of an inch. This means that a film speed of at least 10 times this value must be obtained. Obviously, any light which has a short enough flash duration to eliminate blur caused by film motion at this higher film speed will have no difficulty in stopping the motion of objects going at much higher speeds than those that will be encountered in this application.

Investigation of the minimum possible effective duration that could

be obtained from specially designed flash lamps indicated that 1 to 2 microseconds was the shortest flash that could be anticipated. This duration permits a film speed of from 25 to 40 ft per sec to be used safely in the camera. On this basis the value of 35 ft per sec was selected as the design objective.

It will be seen that there is no possibility of getting 3000 full-sized frames on a 35-ft strip of 35-mm film. In fact, the permissible frame height is only about $^1/_8$ in. instead of $^3/_4$ in. On the other hand, the dimensions of the tank and the possible camera installation indicated that it would be very desirable to have as large a frame height as possible in order to cover the working depth of the water. The obvious way to solve these conflicting requirements appeared to be to use one of the standard tricks long employed with flash-lamp illumination, *i. e.*, to provide a black background and take multiple exposures. This is permissible in the present application since the speed of the body under study will never be high enough to cause images from successive flashes to fall on top of one another if the film moves as much as $^1/_8$ in. between exposures.

The second important characteristic of the flash lamp for such use is the intensity of the illumination. It is apparent that this intensity must be extremely high to produce an image of reasonable density in the very short flash time available. The magnitude of the problem can be seen more graphically if the operation of this type of equipment is compared to that of a hypothetical motion picture camera of the standard type using a normal shutter, but operating at a speed of 3000 pictures per sec. Such a camera would probably have a shutter opening of about 180 deg, which corresponds to an effective exposure time of $^1/_{6000}$ of a second. Such a short exposure would certainly require very-high-intensity illumination if a reasonably good negative were to be secured. However, $^1/_{6000}$ of a second is a little over 160 microseconds. This means that, for a flash duration of one microsecond, the intensity must be at least 160 times as great as would have been necessary with a hypothetical camera using a normal shutter.

The phrase "at least as great" was used advisedly, since there is some evidence to indicate that the reciprocity law breaks down for such extremely short exposures with the result that even higher-intensity illumination may be required to obtain a satisfactory image on the film. This particular installation imposes some extra demands on the illumination because the pictures must be taken under water

and the long underwater light path means large light absorption. Taken together, these conditions all point to the fact that there is no possibility of securing sufficient illumination from a single lamp capable of flashing as rapidly as is necessary to meet our requirements. Therefore, a synchronized battery of lamps is required, which, although it offers the possibility of solving the problem of sufficient intensity illumination, adds another difficulty of its own. If the flash duration is to be only 1 to 2 microseconds, then, if the lamp battery is to be effective, the lamps must be synchronized to flash simultaneously within a limit of about $^1/_{10}$ of a microsecond.

It may be of interest to consider the physical significance of the duration of the illumination of these flash lamps. The speed of light is approximately 186,000 miles per sec. Thus, in one microsecond, light can travel something less than $^2/_{10}$ of a mile, or roughly 1000 ft. In other words a one-microsecond flash of light is only 1000 ft long, and if two such flashes are synchronized to $^1/_{10}$ of a microsecond, they will run along neck and neck with their noses not over 100 ft apart.

Lens Selection.—As previously stated, the fact that the tank must withstand both pressure and vacuum precludes the use of large windows, hence, the cameras must be mounted very close to the tank. Likewise, the tank must be kept as small as possible to avoid undue expense in its construction and operation. This means that wide-angle lenses must be employed if the number of cameras required to cover the experimental area is to be kept within reason.

At the time the design was started, lenses of one-inch focal length were the widest angle lenses available for the use of 35-mm film. Calculations showed that these lenses would cover the entire vertical field, assuming no refraction at the transition from air to water. However, when refraction was considered, the angle of view was reduced to the place that would necessitate two banks of cameras, one above the other, to cover the total depth of the water. It was obvious that two banks of cameras would introduce very serious complications, such as expense of construction, complication of operation and maintenance, and increased difficulty in analyzing results. Therefore, a more acceptable solution of the problem was sought. The obvious method of attack was to find some way of eliminating the reduction in the field caused by the refraction at the air-water interface, since without this refraction a single bank of cameras would be sufficient to do the job.

A possible solution seemed to be the use of spherical windows with

which all the light rays will pass through the interface at an angle of 90 deg and therefore suffer no refraction. This possibility was referred for analysis to Dr. Leonard M. Ross, consultant for Mt. Wilson Observatory.

A series of careful calculations showed that spherical windows were feasible and that the optical distortion would be no worse than in air if a satisfactory radius of curvature were employed and if the camera lens were mounted so that its front nodal point was at the center of curvature of the window. This combination results in a slight decrease in the field of view of the lens, since the addition of the spherical window is equivalent to adding another element to the lens system. Its effect is to decrease the apparent distance between the original lens and the object. Thus, for example, if the distance from the lens to the object is actually 12 ft, the lens must be set for a focal distance of about 2 ft when used with the spherical window. For a one-inch lens, this decreases the field of view about 4 per cent, which is not very serious.

Film-Magazine Requirements.—The normal type of film magazine for a motion picture camera is, of course, one which uses two spools, a supply spool for the unexposed film and a take-up spool for the exposed film. However, this system is not well adapted to film speeds as high as 35 ft per sec. To obtain such a speed starting with the film at rest requires a leader many feet long, even though the spools are accelerated as rapidly as is possible without film breakage. Decelerating the film at the end of the exposure is also a problem if fraying of the film and the consequent filling of the camera with small film fragments is to be avoided.

The installation contemplated here offers the unique feature that the cameras are looking into a completely dark tank until the flash illumination is started. This makes possible the use of an endless-belt type of magazine into which the required amount of film for one run can be loaded and cemented into a continuous strip. With such an arrangement the film can be run through the camera over and over again, thus making it possible to accelerate the film at a completely safe rate until the desired speed is reached. This speed can be set exactly and held without variation during the time of the exposure, after which the film can be decelerated and brought to a stop with no danger of damage. Such a system appeared particularly desirable for use with a bank of cameras, since it would not only reduce the film consumption, but also the danger of film breakage and

similar troubles, and thus would increase the possibility of obtaining successful records from all cameras.

The main requirements for the film drive have already been in dicated, *i.e.*, smooth acceleration and deceleration to prevent damage to the film. However, the fact that this film was to be used for precise measurements made it desirable to maintain a constant film speed during the exposure and also a fixed relationship between the film speed and the number of flashes. This latter requirement is, of course, equivalent to the specification of a constant frame size, and, if it can be made to work satisfactorily, it offers a possibility for the development of a relatively simple projector to present the record in the form of ultra-slow-motion movement.

Since these cameras are to be used as measuring instruments, they must be as carefully aligned and as permanently fixed to the windows of the tank as would be necessary for the use of any other optical measuring instrument. This means that the magazines must be of the daylight-loading type since the cameras cannot readily be removed from the tank and taken into the darkroom for reloading. Obviously, if a daylight-loading type of magazine is to be used, each strip of film will contain a small exposed portion which can also be made to contain the splice. To obtain a complete record of the experiment, measurements must be started at the beginning of the entire unexposed length of film, or, in other words, just after the exposed portion, including the splice, has passed through the camera. If this condition is to hold simultaneously for all of the cameras in the battery, then the lengths of the film in all of the magazines must be identical; *i.e.*, they must have the same number of sprocket holes per film belt. If this condition can be otained, then all of the splices in the exposed portions of the film can be set at the same relative position and will maintain this relation during the entire run.

To secure identical lengths of film in each magazine requires a precision-loading technique, a prerequisite of which is an exact means for measuring the film being loaded. Furthermore, an endless-belt type of magazine demands a fixed predetermined pattern of threading which must be maintained during the loading and unloading cycles. The best way of meeting these rather complicated demands appears to be through the construction of a magazine loader which would incorporate a film-measuring device, a splicer, and film supply and take-up rolls of sufficient size to load the entire camera battery a number of times. Since this auxiliary piece of equipment is necessary

for the successful operation of the camera battery, it can be considered as a necessary part of the camera equipment, and therefore a description of it will be included.

Description of the Camera.—The camera itself is basically a very simple device. Inherently, it has a fixed focus since with the lens wide open the depth of focus is sufficient to cover the entire operating portion of the tank. The camera consists essentially of two elements, the lens and its mount, including the spherical window, and the film drive which incorporates the special gate at the focal plane. Fig. 2 shows a sectional elevation of the camera itself.

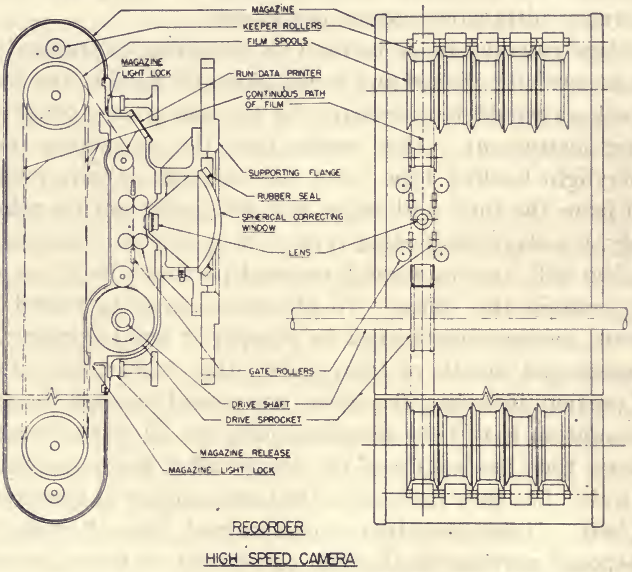

FIG. 2. Sectional elevation of high-speed camera.

The lens system can be seen in this figure. It will be observed that the lens is mounted in a barrel having a fine pitch thread for initial focal adjustment. The mounting for the spherical window has been given a great deal of consideration. It should be remembered that water is always in direct contact with the convex side of this window. The concave side, as well as the camera, is in air and remains at atmospheric pressure. On the convex side the water pressure may vary from about 14 lb per sq in. below atmospheric pressure to 45 lb per sq in. above it. Since this spherical window is actually an

auxiliary lens for the camera, precise alignment must be maintained at all times. This is ensured by installing the glass in direct contact with a metal mounting flange. Leakage is prevented by the use of a rubber-ring gasket of the unsupported-area type which works equally well for either positive or negative pressures. Fig. 3 shows the appearance of this spherical window as seen from the inside of the tank. The camera lens is visible in the center of the window.

The film path through the camera is very simple, as may be seen in Fig. 2. It enters the camera near the top, passes over a roller which guides it into the focal plane, goes down through the gate to another guide roller, which feeds it to the drive sprocket. The film has a 90-deg wrap on the drive sprocket and leaves it with a correct

FIG. 3. Spherical window as seen from inside of tank.

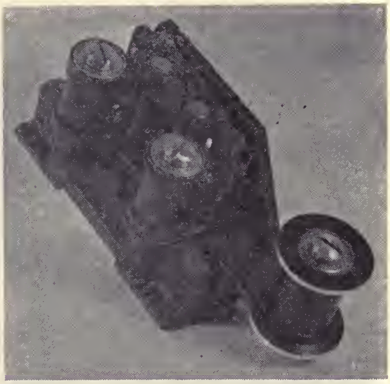

FIG. 4. Detail of roller guides for focal plane.

alignment to go directly to the first idler spool in the magazine. The gate itself is of special design to operate at the highest film speed that is used. It was believed that it would be extremely difficult, if not impossible, to prevent film damage if rubbing contact were permitted at any point in the camera with a film speed of 35 ft per sec. At the same time, exact positioning of the film in the focal plane was required in order to secure quantitative measurements from the records.

The system of roller guides, seen in Fig. 2 and shown in detail in Fig. 4, was developed for this purpose. It will be noted that the rollers are relieved between the sprocket holes so that they do not touch the film in the active area. All of the rollers in the camera and magazine are so relieved. Edge rollers are provided to define

precisely the lateral position of the film. A double pair of rollers at entrance and exit was found necessary to flatten the film properly as it passes through the focal plane. Tests showed, however, that this construction alone was not sufficient to ensure complete flatness of the film under all conditions since a slight lateral curvature tended to persist. The only successful method yet developed of eliminating this curvature has been through a rough control of the humidity by use of humidifying pads in the magazine. Fig. 5 is a side view of the camera showing the loading door. The opening and closing of this door also moves interlocking pins which operate the light locks so as to prevent accidental exposure of the film.

Fig. 6 shows the external view of the film magazine. It will be noted that it seems disproportionately large compared to the size of the camera. This is, of course, because of the fact that the film is laced as an endless belt in the magazine. Fig. 7 (*a*) and (*b*) shows the external construction of the film rack with the film laced in place. The run on which the film enters and leaves the camera is a straight vertical run, whereas most of the others are diagonal. The alternate use of large and small spools on both the upper and lower shafts eliminates the possibility of the film's touching and rubbing on the crossover points. The shaft which carries the lower set of spools is loaded both by gravity and by an auxiliary spring in order to secure the desired film tension. The film lacing shown in Fig. 7 utilizes the maximum capacity of the magazine. This lacing can be modified to accommodate shorter lengths in case a full-length film strip is not necessary.

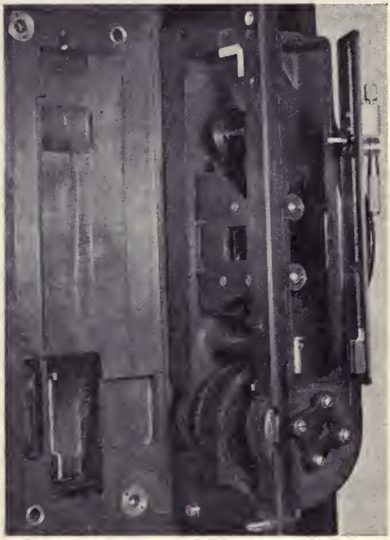

FIG. 5. Side view of camera showing loading door.

FIG. 6. External view of film magazine.

(a)

(b)

FIG. 7. External construction of film rack with film laced in place. (a) Front. (b) Back.

Camera Drive.—Fig. 8 is a general view of the bank of five cameras mounted on the side of the tank. The common drive shaft can be seen passing through all of the cameras. This drive shaft was designed for high torsional rigidity to eliminate any appreciable displacement angle between the drive sprockets of the different cameras. To prevent any binding at the bearings, flexible universal joints of the metallic-disk type have been provided at each side of each camera. When the battery is being operated, with full magazines running at the maximum speed of 35 ft per sec, the angular displacement of the drive sprockets between the first and last cameras in the bank is less than 0.04 deg, which is equivalent to 0.001 in. of film travel. For most conditions of operation, this introduces an error in the measurements too small to be significant. However, it can be corrected very easily by adjusting the corresponding projectors to have the same angular displacement with respect to the first camera in the bank. The synchronous drive motor can be seen on the extreme left of the drive shaft. Fig. 9 is a more detailed view

FIG. 9. Synchronous drive motor.

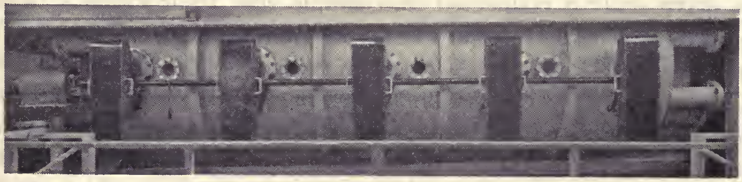

FIG. 8. Bank of five cameras mounted on side of tank.

of this motor. It will be seen that there is an electric brake on each end of it. These brakes are used to secure the low and smooth accelerations and decelerations, required to prevent film damage. It will be observed in Fig. 9 that the entire motor is mounted on trunnion bearings so that it can rotate. The power supply is brought to it through a set of three slip rings mounted on the outside of the motor frame. The electric brake on the right-hand end operates on the motor shaft; whereas the one on the left-hand end works against the motor frame. The operation of this system can best be seen by following through a complete cycle, as follows:

Consider that the cameras are all loaded with full magazines and that everything is stationary but ready for a normal photographic run. The motor-shaft brake is then clamped and the motor-frame brake released. The starting switch is then closed, applying power to the motor. Since the rotor and drive shaft are clamped, the motor frame starts to revolve on its trunnion bearings. It accelerates up to normal speed and synchronizes. Next the shaft brake is released, making it possible for the rotor and drive shaft to turn. The frame brake is then applied gradually at a predetermined rate. This slowly brings the motor frame to a stop while the rotor with the drive shaft, camera sprockets, and film magazines all come up to full synchronous speed. The cameras are now ready to record the results of the experiment. This is done by launching the body, the motion of which is to be recorded, and simultaneously turning on the battery of flash lamps.

When the exposure is made and the record obtained, the film is brought to a gradual stop by a reversal of the above procedure; *i.e.*, first the frame brake is released so that the frame is free to turn, then the shaft brake is applied at a gradual rate, and the film in all the cameras brought to a standstill. By means of a series of interlocking relays, all of these operations are performed automatically after the starting or stopping switch is closed by the operator.

One further refinement is incorporated in the procedure. The camera drive shaft is connected to a simple gear train which acts as a counting device to keep track of the location of the film splices. This counter is interlocked with the main control of the experiment itself so that the experiment can be started and the flash lamps energized only immediately after the film splice and the exposed section of the film have gone through the camera. This interlock ensures that full record of the phenomenon under investigation will always be obtained at each run.

Magazine Loader.—The film magazines are all detachable from the cameras and may be taken to the darkroom for loading. However, they are large and bulky and quite heavy, even though made of aluminum. As explained previously, a special loading device is necessary in order to preserve the threading pattern and also to ensure that each magazine is loaded with exactly the same length of film. A little study showed that it would be simpler to design the magazine loader so that it could be brought to the magazine, rather than to take the magazines into the darkroom for reloading. To facilitate this operation, a special bracket was installed at each camera to permit the magazine to swing down in a horizonal position

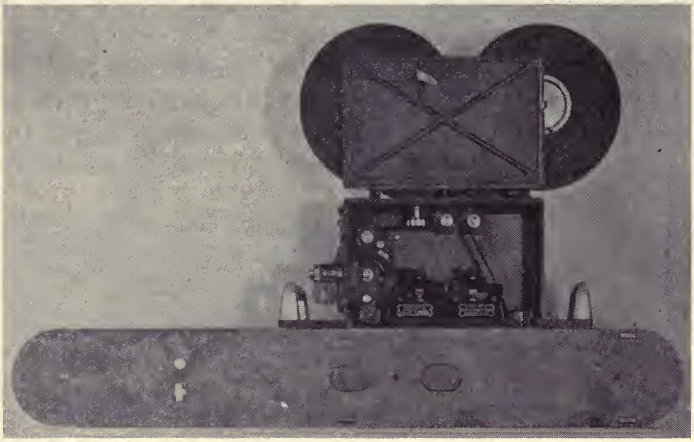

FIG. 10. Magazine in loading position.

behind the camera. Fig. 10 shows one of the magazines in this loading position with the loader mounted in place on it. A standard Mitchell 1000-ft camera magazine is used for the unexposed and exposed film storage. The lower section of the loader contains the sprocket-hole counter and the splicer.

The operation of the loader is as follows: It is first placed upon the magazine using the same locating dowels that position the magazine on the camera. The loading-film loop containing the splice projects out of the magazine into the loader. This loop is now broken. One end of it is spliced to the end of the exposed film going to the take-up spool. The other end is spliced to the unexposed film coming from the supply spool. The loader door is now closed, which opens the

light locks to the magazine and to the supply and take-up spools. The operating crank is then turned until the exposed film has been drawn out of the magazine and a reload of unexposed film drawn in. The correct amount of film is indicated by the reading of the sprocket-hole counter. The loader door is then unlocked, which closes the light locks into the camera and film magazine. The film is then cut from the feed and take-up spools and a splice made to form the endless belt in the camera magazine. This splice is made at the exact sprocket hole indicated by the counter. It will be seen that all of the splicing and cutting can be done in daylight since the only film exposed is that section which it is necessary to use in any case during the threading of the loop through the camera gate and drive sprockets.

Flash Lamps.—The flash lamps are straight gas-filled tubes approximately 8 in. long and are made of quartz. Quartz tubes are necessary because of the tremendous amount of energy that is fed into them to produce the flashes. The use of quartz makes

FIG. 11. Flash lamp.

possible much longer runs than could be obtained by Pyrex or any other type of glass tube. The characteristics of these tubes limit the length of record that can be secured when being operated at flash speeds of 1000 per sec or greater. Their effective limit is about 3000 flashes. At this point they become so hot that the duration and intensity of the flash is seriously affected. Continued operation beyond 3000 flashes quickly results in softening and final collapse of the tube. Fig. 11 shows one of these tubes.

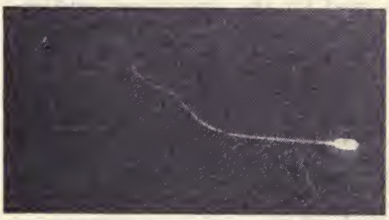

FIG. 12. Time-intensity record of flash produced.
Horizontal time scale: 2 divisions per microsecond.

Fig. 12 is a time-intensity record of the flash produced. This record was obtained by observing the flash with a photocell driving a synchroscope. It

will be seen that the duration at peak intensity is approximately one microsecond and the effective photographic duration between 1 and 2 microseconds. The energy input to the tube is approximately one joule per flash. Expressed in other units, this means that at a flashing rate of 3000 per sec, each tube requires an amount of energy equivalent to a continuous input of 3 kw. If the duration of each flash is assumed to be one microsecond, the light is on $^{1}/_{333}$ and off $^{332}/_{333}$ of the total time. Thus the rate of energy input to one tube during each flash is about one megawatt (1000 kw).

The flash tube is made in the form of a line source because the area to be illuminated is rectangular. To utilize the light as efficiently as possible, each tube is mounted in a special reflector as shown in Fig. 13. These reflectors are constructed of Lucite, cemented together and then aluminized by the vacuum-sputtering technique. The cross section of the reflector is so designed that the light is distributed as uniformly as possible over the depth of working section in the water tank. These lamps are normally used in banks, jointed together as shown in Fig. 14. This construction makes it possible to insert them into Lucite tubes of about 8 in. in diameter. These tubes run longitudinally through the tank and are provided with stuffing boxes at each end to prevent leakage. Thus, the lights themselves are in air at atmospheric pressure at all times, but so far as illuminating the tank is concerned, they act as if they were under water.

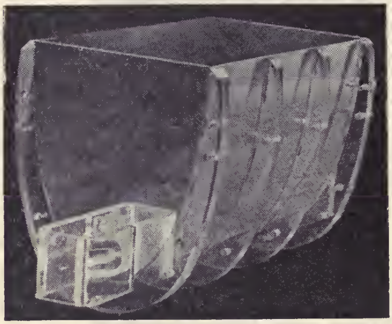

FIG. 13. Flash tube mounted in reflector.

A detailed description of the power supply and control circuits for these lamps is beyond the scope of the present paper. They are basically the product of Prof. Harold E. Edgerton and his assistants

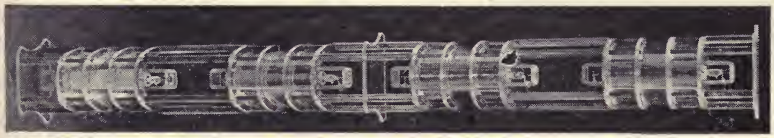

FIG. 14. Bank of high-speed flash lamps.

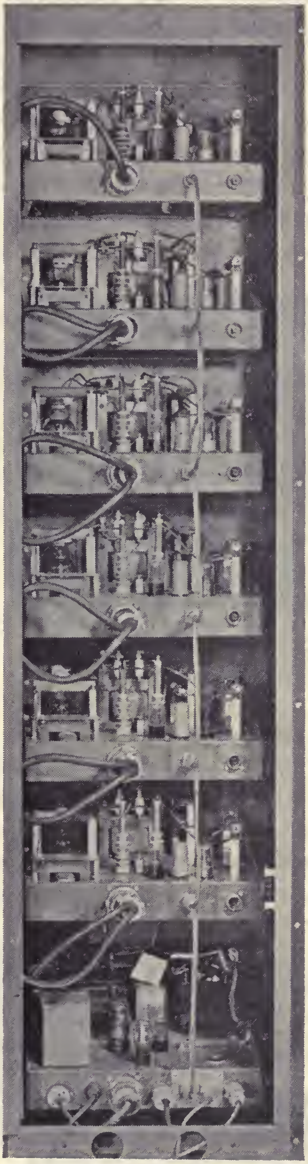

FIG. 15. Battery of six control units.

at Massachusetts Institute of Technology, who are pioneers of many years standing in this field. Rather extensive modifications of the normal equipment were incorporated in this development for the Hydrodynamics Laboratory, which shortened considerably the duration of the flash and also made it possible to operate the lamps with cables of varying lengths up to 100 ft connecting them to their respective control units. Measurements taken during operation indicate that the circuits employed in the control units showed deviations in flash time of 0.1 microsecond or less. This means that the flash duration of the entire battery of lamps was not over 10 per cent longer than that of any individual tube. Each lamp requires a separate control circuit. Fig. 15 shows a battery of six such units with the cabinet door open to give a view of the interior. In all, seven batteries have been installed, giving a maximum of 42 lamps that can be operated in synchronism.

The fundamental principle of operation is very simple. Each unit contains a high-voltage capacitor, which acts as a power reservoir to supply the necessary energy to operate the light during the flash period. Power is poured into this capacitor during the relatively long period between flashes. At the time of the flash, the entire amount of energy stored in the capacitor is discharged through the lamp tube through a high-capacity Thyratron tube, which is used for the

control switch. The power source for charging all the capacitors of the lamp battery is a 120-kw three-phase, high-voltage rectifier which supplies d-c power at any desired voltage up to 6000. The control circuits incorporate voltage doublers, thus the lights themselves can be operated at any desired potential up to 12,000 v, depending on the light intensity desired. Needless to say, circuits operating with d-c voltages and capacitors of these magnitudes require safety precautions for the operating personnel.

Operating Experience.—The cameras that have been described and their associated equipment are now coming into full operation. It is felt that the installation will prove to be a very keen tool for the study of high-speed hydrodynamic phenomena. It may be of interest to know that one of the major difficulties that has had to be overcome in obtaining satisfactory results with this equipment has been the securing and maintaining of a supply of water having satisfactory clarity. It will be remembered that the length of the light path from the lamps to the object under study and back to the film in the camera is about 25 feet.

Measurements made with dust-free double-distilled water, purified with the utmost care, indicates that a layer of such water one foot thick will transmit 99 per cent of light that falls on its face. At first this sounds well, but it must be remembered that the light path is 25 ft long. To calculate the light transmitted through 25 ft of water, it is necessary to raise the coefficient of light transmission to the 25th power: 0.99 to the 25th power is 0.78. In other words, one fourth of the light will be absorbed and three fourths will reach the camera. The corresponding absorption for a 25-ft air path is immeasurably small. Thus it will be seen that the very best water obtainable absorbs an appreciable amount of light.

However, the Laboratory has made comparative measurements of a number of different samples of water, all of which appeared very clear to the eye when viewed in 5-gal containers. It was found that carefully filtered de-aerated city water stored in glass until the time of measurement had a transmission coefficient of 0.95. Identical water stored in a rubber-lined tank for two weeks showed a transmission coefficient of about 0.65. Another of the same samples stored for the same length of time in a tank painted with high-grade zinc chromate showed a transmission coefficient of about 0.85, but, in addition, it was found that the transmission in the blue was completely eliminated.

Table 1 shows a comparison of these various water samples on the basis of a 25-ft light path. An examination of this table makes only too evident the absolute necessity of securing a clear water supply for underwater photography which requires an appreciable light path. A major step in the solution of the problem for the Hydrodynamics Laboratory tank has been to line the tank completely with Koroseal of a type that was first subjected to rigorous tests to prove that it did not affect the water stored in it in any way.

TABLE 1

Water Sample	Transmission Coefficients per Foot	Percentage of Light Transmitted per 25-Ft Path
Filtered distilled	0.99	78
Filtered city supply	0.95	28
Zinc chromate paint container	0.85	2
Rubber-lined container	0.70	0.01

PHOTOGRAPHING THINGS TO COME*

M. W. WARREN**

Summary.—*This paper deals with future AAF requirements for motion picture equipment to meet such extremes as exposures at altitudes of 100,000 ft and speeds of 1500 mph. It discusses three wartime cameras which are focused on things to come.*

Approximately eleven years ago, Colonel Goddard of Air Materiel Command addressed the Society of Motion Picture Engineers. At that time, looking forward to the then spectacular future, he prophesied photographic aircraft traveling at the rate of 300 mph. That was eleven years ago. Hiroshima and Nagasaki were but names on a map. Operation Crossroads and the White Sands guided-missile projects were unknown. Today, while we talk about aircraft traveling at the rate of 1500 mph at altitudes of 100,000 ft, there are future projects and operations of which we can only guess. One fact, however, which was true eleven years ago is still true today—the Air Corps must and will be ready to photograph the things to come.

* Presented Oct. 25, 1946, at the SMPE Convention in Hollywood.

** Air Materiel Command, Wright Field, Dayton, Ohio.

While tomorrow's photographic requirements are still subject to conjecture, there are some clear signposts. Aerial cameras must operate from a few feet off the ground to miles above it. They must literally be able to stop the effects of supersonic speeds; and finally, they must be able to be airborne whether by aircraft, rocket, or projectile. The major problems are height, speed, power, space, and weight. Let me reverse the problems, and touch on the last ones first. Throughout the war we experimented with longer and longer focal lengths, which has meant consistently larger and heavier cameras. We are now testing a 100-in., $f/10$, 600-lb camera, and in our agenda is a 240-in. camera. Obviously there has to be a limit. Even though that limit may be far removed, it is important that we realize the time is coming when cameras borne in aircraft may be outmoded and aerial photographers out of jobs. Already, remotely controlled 35-mm turret-installed cameras have been used successfully at Bikini, in the drone flight from Hawaii, and in the White Sands project. In the future, with speeds beyond sound, the design, cubage, and weight of photographic equipment will be increasingly important.

Our next problem is to capture clear pictures at rocket and jet speeds. Cameras with increased focal lengths comprise one method we are using. We are also experimenting with the possibility of a variable-opening shutter with maximum lens opening so that we may obtain the highest possible shutter speed for varying light conditions. We already have under procurement a high-cycling strike camera with a shutter speed of $^1/_{2000}$ of a second. In the future we shall be experimenting more and more with electronic means for taking pictures at high speeds. Experiments are being conducted on films having deep red sensitive emulsions in order to attain greater film speeds. At Bikini, our cameras were required to photograph every millisecond of the atomic bomb blasts.

Man's continual climb toward stratospheric heights has presented us with other problems, and not the least of these is temperature control at high altitudes. We have made use of thermostatically controlled heating elements and automatic air-density compensating elements.

The Baker 40-in. telephoto lens is a successful solution to this problem. The rear lens of this camera floats on a link system of small bellows which expands and contracts to change the focus automatically in order to compensate for air pressure and temperature changes.

Among the other problems arising from higher and higher altitudes are corrections for increased aerial haze, vibration, and the manufacture of lenses which will permit pictures of vast areas. In the use of color film, we are working toward films with higher speeds and greater contrast particularly in the blue layer so that we may use sharper cutoff filters to reduce the loss of contrast caused by aerial haze. Pictures taken in jet-propelled aircraft have opened up a new era of aerial photographs having little or no vibration.

In addition, we are continuing to work for a stabilized mount which will ensure absolutely vertical, vibration-free exposures. In the field of wide-angle cameras, one of the most unusual is the Baker Spherical Shell model which permits the taking of photographs that cover an angle of 120 deg, so that when used at a 30,000-ft altitude an area of 300 sq miles is obtained in each exposure. The experimental model, which only recently has been taken out of the secret class, makes use of a 4-in., $f/2.8$ lens that produces the images on a Spherical Shell. The negatives are projected in a special projection printer onto a white acetate base sensitized paper 40 × 40 in. square. Our experiments with guided missiles are providing us with records and information about those regions to which no man has yet ascended. Fortunately, they show that we are on the right track in our high-altitude research.

In some cases we have more than signposts—we have the preliminary models for some of tomorrow's cameras. Specifically, I should like to discuss three models which I believe qualify for the future. They are the *O-5A* Radar Recording Camera, the *A-6* Motion Picture Camera, and the Sonne *S-7* Continuous Strip Camera.

My reasons for including the *O-5A* camera are many. First, it has already been used to obtain valuable atomic bomb data, photograph the pip of the moon, and record the flight of drone planes. Today it is being used in the White Sands project, and to photograph areas covered by clouds, which cannot be photographed with aerial cameras.

Turning from the present of the *O-5A* camera for a moment, let us survey its history. Despite enormous strides and even more spectacular press releases, aviation as late as 1945 was largely a fair-weather weapon and radar navigation left something to be desired. One has only to recall the Battle of the Bulge for substantiating the fact that the entire allied air force was helplessly pinned to the ground by weather while the German artillery had its field day. It was not

until research pointed out that the fault lay not with the aircraft or radar, but with radar interpretation, that real progress was made. You have seen radar maps of cities, coastlines, *etc.*, and probably have wondered how anyone could make sense out of the things—let alone distinguish an island from a battleship. Imagine what it was like when there were no maps!

The *O-5A* camera did not just grow. Many trials had to be made and some errors committed before it first saw the light of radar. However, from the first radar recording camera, which appeared in 1942 (a Kodak *35* with a total of 36 exposures), to the present model, much progress has been made. Today's 35-mm *O-5A*, the joint result of research by the Army, Navy, and MIT, has a 100-ft film magazine which can be replaced in 15 sec, giving thereby an almost unlimited number of exposures. No longer does the operator have to choose which of a few sweeps he can record. A simple push button permits him to set the camera for every sweep, every other sweep, every tenth, or every sixtieth sweep. No longer does the radar operator have to focus the main scope and then focus the auxiliary scope used for the camera. An elbow beam splitter with a color-selective coated surface permits the same scope to be used by operator and camera. Throughout the development of the radar recording camera, we have consistently reduced its size and weight. The *O-5A* model with all its accessories weighs only 25 lb and requires only $^5/_8$ cu ft of space.

Despite this progress, tomorrow's radar recording camera will have to be smaller and lighter, have an even larger film capacity, and be adapted to remote control—perhaps from miles away. It will be used to chart the route for tomorrow's navigation, and provide the road maps for three-dimensional color photography

Among general utility motion picture cameras, my nomination for the future is the *A-6* model. Because AAF motion picture cameras in operation throughout the war did not satisfactorily fulfill all aerial requirements, the *A-6* Model finally was designed. It is a 35-mm camera with operating speeds of 16, 24, 32, and 48 frames per sec and has an 87-deg shutter which permits $^1/_{100}$ of a second exposure when operating at the rate of 24 frames per sec.

Unlike many of the earlier models which were modifications of existing ground cameras, the *A-6* was built primarily for aerial use. As a consequence, special features were required. Among these are a 3-lens turret, which prevents vignetting with lenses between 25 mm

and 6 in., and a critical focusing attachment that can be inserted in the camera directly behind the lens in the "take" position to provide a means for accurately checking the field of view and for bore-sighting the camera. This camera has the ability to operate at temperatures as low as −65 F. Since operators working in low temperatures require gloves, which are often heavy and cumbersome, a special magazine was developed to permit easy loading of the camera. In addition, special start and stop buttons were designed for gloved operation. The buttons are placed $2^1/_2$ in. apart, and the stop button remains in the lock position until it is depressed. Taking into consideration the difficulties of aircraft installation, the *A-6* is designed to operate in any position in regard to horizontal and vertical axes, and a direct image view-finder permits the field to be viewed as far as 12 in. behind the view-finder. To provide further utility, the *A-6* may be operated by a detachable motor, a spring motor, or by means of a hand crank. An adapter is provided for tripod use.

Although the performance record of this camera has yet to be written, plans for future development are already under way. Our main objective is to provide a motion picture camera with the greatest possible film capacity and focal length, and at the same time, have it require the smallest possible amount of space. Along this line we are working on 16- and 35-mm combat recording cameras which will provide speeds of 48 to 96 frames per sec, operate in any position, and have erector systems which will permit normally viewed projected images regardless of the taking positions. Another motion picture camera on the docket is one having an automatic diaphragm with a photoelectric cell that operates from reflected light to adjust a variable-opening shutter. Development is also under way for a camera mount which will permit varied installation and, by means of servomotors, permit the camera to be sighted by an automatic computer.

Perhaps the most spectacular camera, however, is the *S-7* Sonne continuous-strip stereoscopic camera. While it is not a motion picture camera in the true sense of the word, it does have a moving picture film feature. The most revolutionary feature about the camera is its lack of shutter. The film moves at a controlled speed past an adjustable slit permitting the desired exposure and at the same time compensating for ground motion. Another advantage is that it provides an exposure 200 ft long by $9^1/_2$ in. wide without breaks in the continuity. Because of the ground-image compensation

and the continuous-strip features, this camera has been ideally suited to low-altitude, high-speed photography. Its history is filled with spectacular triumphs, of which I shall mention but a few. It was used to obtain color stereoscopic pictures of the beaches of Okinawa and the resulting exposures were used to chart the invasion. When the landings had been made successfully, the heights of the underwater reefs and sea walls obtained from the pictures were accurate to fractions of a foot. Beside making history in the Pacific, this camera was used to prepare the grounds for the Normandy invasion. At Bikini, with several modifications, it provided facts about nuclear science which would have been unattainable otherwise.

The value of pictures taken at low altitudes and high speeds with stereoscopic features makes this camera of great value to the future. Today, despite the tremendous amount of photographic reconnaissance accomplished, only one fifth of the world has been charted—and that, for the most part, in black and white. In order to pinpoint projectiles, the first requirement will be for precise and accurate pictures taken only a few feet off the ground. Color pictures will divulge the product of a manufacturing plant by its smoke, residue, or raw products, and stereo pictures will reveal accurate heights and depths. These are necessities for tomorrow.

Already we have flown the *S-7* Sonne Strip Camera at speeds of 580 ft per sec, only a few feet above the tree tops, and have made plainly visible nails in the planks of bridges and stickers on the windshields of cars. We must be able to do the same thing traveling at speeds faster than that of sound.

Despite its satisfactory record, the strip camera is slated for future modification. Instead of interchangeable cones of a single 6-in. lens dual 88-mm, 100-mm, or 5-in. lenses, stereo cones accommodating two 12-in. and two 20-in. lenses are under procurement. Designs have been drawn up for a nonbanding precision film-drive mechanism, a stabilized mount, and a film capacity of 400 ft. Under development is a new type stereo-strip camera which employs a single 40-in. *f/5* telephoto lens.

This camera will have two slits to provide stereo photographs. The present system uses two lenses located fore and aft in respect to a single slit. Two separate rolls of 400-ft film will be used. It is expected that this camera will permit extreme high-altitude photography in jet-propelled aircraft.

Let me at this point repeat a statement I made earlier: we are

proud of these cameras, and the entire photographic industry may justifiably be proud of its record. However, these cameras of which we are so proud are simply crude, experimental models of tomorrow's photographic equipment. The past and the present belong to historians. The future is our concern. Years of hard, and often discouraging, research have brought photography into its own. There is no other way, no primrose path, into the future. Research and research alone will get our cameras into the stratosphere to road-map the future at supersonic speeds.

A STABILIZATION SYSTEM BY RATE MEASUREMENT*

AVERY LOCKNER**

Summary.—*Wartime requirements of airborne armament led to the development of a successful system of stabilization which, when applied to gun turrets, enabled gunners to track a target with greater ease. At present, the system is being adapted to the stabilization of aerial cameras to overcome certain faults inherent in present photographic techniques. This paper discusses the problems and describes the system applied to aerial photography.*

The techniques of motion picture photography and aerial photography appear to have at least one problem in common. Any motion of the studio camera mount during the interval of making a shot will produce undersirable results in the final pictures. In aerial photography any deviation of the airplane from smooth flight will cause tilt of the photographs and also blurring of the photographs resulting from image motion during exposure. It has been generally recognized that some form of stabilization of the camera mount would alleviate this condition, if not provide a satisfactory and complete solution.

The problem of developing such a system of stabilization has received the attention of many talented organizations over a long period of time. To date, no practical stabilizer has been evolved which gives any measure of satisfaction to the critical demands of the photographic engineers. Our own engineers have directed a great amount of energy in this direction at various times over the past twenty years

* Presented Oct. 22, 1946, at the SMPE Convention in Hollywood.
** Fairchild Camera and Instrument Corporation, Jamaica, N. Y.

with no apparent success. However, the requirements of wartime aircraft armament development received a great amount of emphasis in our engineering laboratories. During the course of the many developments completed in that field, a successful system of stabilizing aircraft gun turrets was evolved. It appears that it may be possible and practicable to modify this stabilization system to provide a fairly satisfactory means of stabilizing a camera mount.

Early gunsight computers used in aerial gun turrets had to start from many assumptions. The greatest assumption was that the aircraft always should fly straight and level. Any deviations from such straight and level flight would mean that the gunner would have to be adjusting his turret constantly to take care of any aircraft maneuvers. Such variations from straight and level flight caused false information to be fed to the computers, and caused constant confusion to the gunner, since he never could predict completely the direction and magnitude of any such deviation from prescribed conditions.

At the same time, the bomber, when participating in a dog fight, was literally a sitting-duck target for any enemy aircraft. The enemy knew very well that once the bomber was to take a certain course, it could not deviate from that course without upsetting the accuracy of all the armament installed in the bomber. This vulnerability made it very desirable that some new instrument be developed which would enable the bomber to fly a devious and eccentric course in order to avoid the hazards of being a so-called sitting-duck target without at the same time compromising the accuracy of its armament.

Consequently, early in the war, a very well-defined requirement arose for some system of stabilization to be developed so that a turret installation in a bomber or fighter would remain in a fixed position in space, irrespective of any maneuvering tactics the carrying aircraft might assume.

This problem of supplying stabilization was approached from many angles. All solutions had one thing in common—a means of overcoming the primary control of the power system of the turret to correct its motion in reference to the airplane so that its control might be established in terms of outside space. Such control in terms of outside space is predicated on some means of measuring position or rate of the turret in outside space. Of the many means possible, the two most commonly used are a vertical gyroscope and a rate gyroscope.

The Fairchild stabilization system employs a rate-measuring gyroscope as a control instrument. Two gyroscopes are used and are so

oriented that rates are measured in the horizontal and elevation planes. These two instruments are identical and interchangeable.

The gyroscope rotor is driven by a speed-controlled electric motor and revolves at 12,600 rpm. This rotor is mounted in gimbals and is restrained by calibrated springs with a single degree (or plane) of freedom permitted. An angular motion perpendicular to this plane of freedom results in a gyroscope precession directly proportional to the applied angular velocity. When such gyroscope precession occurs, the magnetic circuit of a balanced *E* pickoff becomes asymetrical, and an ouput voltage is developed. Any angular rate up to 33 deg per sec has a corresponding gyroscope output voltage. Moreover, the direction of the angular motion is determined by the phase relationship of the output signal.

By maintaining this gyroscope output at a given level, any desired rate in space can be established. Should any deviation from the desired rate occur, an immediate change in gyroscope output is registered.

The method used to select and maintain this signal level is as follows:

The gyroscope *E* pickoff is supplied by a 110-v, 400-cycle source of power, usually the aircraft inverter. This same source of power is used to supply a transformer delivering its secondary voltage to a potentiometer geared to the hand controls of the turret. Any rotation of the hand controls to require a velocity from the turret rotates this potentiometer. This rotation results in a voltage output increasing from zero at the center of travel. Equal displacements right and left of the center produce voltages equal in magnitude but opposite in phase.

For a given rotation of the hand controls, a given voltage is produced. The difference between this voltage and the gyroscope output is fed into an integrating servo whose output turns another potentiometer. This servo-controlled potentiometer, through an amplifier, controls an amplidyne generator, and finally, the turret rate. The system compares the gyroscope output with the chosen output of the hand-control potentiometer which represents the desired rate in space. If any difference exists, the servopotentiometer rotates, changing the turret rate until the gyroscope output just equals that of the hand-control potentiometer. Any change of angular rate of the turret from an external cause, *i. e.*, rough air or turning of the aircraft, will result in a changed signal from the gyroscope. Its voltage

will no longer be equal to that of the hand-control potentiometer and an appropriate correction in turret rate will be initiated through the servo-controlled potentiometer.

Quantitative measurements made on this system indicate that the activating or drive mechanism of the turret presents the most serious drawback to a good stabilizing system. A drive system that is quick to respond to changes in an input signal will accumulate a much smaller error in velocity or acceleration than a system with sluggish response. The amplidyne generator drive used in the system under discussion has a rather sluggish response. At present, the same system philosophy is being adapted to a hydraulic system. Because of the quicker response of the hydraulic system, more accurate results have been achieved, in that both velocity and acceleration errors have been reduced by a considerable amount.

A stabilized mount for aerial cameras, which would keep the camera axis more nearly vertical, would result in considerable saving in the cost of aerial mapping projects. The gains from a good stabilization system would be twofold. First there would be the gain resulting from elimination of many cases where missions have to be reflown because of extensive tilt in the photographs, and second, a gain in resolution or sharpness of the picture by elimination of angular motion of the camera during exposure.

The ultimate solution to the camera-stabilization problem can be broken down into two distinct parts. First would be the development of a system which would automatically hold the camera in a fixed attitude at all times. The second would be a system for determining a true vertical reference axis and a follow-up system capable of trimming the camera axis always to be parallel to the vertical reference. For practical usage, much is to be gained from a system which will retain the camera axis at a given tilt over a long period of time. Blur of the photographs resulting from roll or pitch of the airplane would be eliminated. Also, considerable saving in time and cost can be made in the rectification of the photographs.

Based on experiments made in the stabilization of aerial gun turrets, we expect to produce a system of camera stabilization that will automatically maintain the camera's axis in a fixed attitude regardless of tilts, rolls, pitches, or any maneuver of the aircraft. The system will have manual controls to permit trimming of the stabilized camera. Thus a manual adjustment of the camera's attitude can be made so that the stabilization system could be started at any time.

Regardless of the original camera's attitude, the camera axis could be changed at will to make it as nearly vertical as possible within the limits of existing conditions. Precision spirit levels could be mounted on the camera to indicate tip and tilt so that by selecting a time when the aircraft was flying straight and level, a trimming operation could be made. Depending on the sensitivity of the system, any drift after erection would be appreciably small and result in a major gain for practical usage.

We have received inquiries from time to time from professional people in the motion picture industry regarding their problems in regard to a stabilized camera mount. We feel that problems existent in that field very closely parallel those of aerial photography in many instances. It is safe to assume that the techniques of the stabilization system described above could very well be applied to the stabilizing of studio camera mounts. It is probable that a practical system from the point of view of cost, weight, space, and performance could be developed successfully.

SMPE STAFF CHANGES

Carrying out the Society's current expansion program, which was started by Harry Smith, Jr., recently resigned Executive Secretary, the Society has made several changes in its Headquarters Staff and in the organization of its offices. Boyce Nemec, former Engineering Secretary, has been appointed Executive Secretary, and his office staff has been increased by the addition of a full-time Editor and a Staff Engineer. In addition, responsibility for the business and financial records and physical operation of the Society's Headquarters have been formally assigned to an Office Manager.

BOYCE NEMEC
Executive Secretary

Boyce Nemec, newly appointed Executive Secretary of the SMPE, has been active in the technical end of motion pictures for over a decade. He was a member of the Visual Education Department of the University of Minnesota before joining the Army in 1941, when he was assigned to the Signal Corps Training Film Production Laboratories at Fort Monmouth, New Jersey.

Mr. Nemec was instrumental in forming the War Committee on Photography; served as secretary of the Interim Armed Forces Committee on Photography in its initial stages; and represented the Signal Corps' engineering and procurement interests on the War Committee, Federal Specifications Committee and Joint Army-Navy Specifications Board as chief of the Signal Corps' Photographic Specifications Unit.

On his discharge from the Army, Mr. Nemec came directly to the SMPE as Engineering Secretary to carry out the Society's greatly enlarged standardization and engineering program.

SMPE STAFF CHANGES

MARGARET C. KELLY
Office Manager

Margaret C. Kelly was born in Wilkes-Barre, Pennsylvania, and attended Wyoming Seminary and Bucknell University. She came to the SMPE over four years ago to be Financial Assistant. In line with the Society's expansion program, Miss Kelly recently was made Office Manager. Before joining the staff of the SMPE she was Office Manager for the Lion Chemical Company.

THOMAS F. LO GIUDICE
Staff Engineer

Thomas F. Lo Giudice, Staff Engineer, received his motion picture experience in the engineering department of the International Projector Corporation. There he did experimental and development work on motion picture projection and sound systems and on naval underwater sound equipment. Later he served in the electronics branch of the U. S. Coast Guard dealing with radio, radar, sonar, and loran gear. He recently received the B.E.E. degree from the Polytechnic Institute of Brooklyn, where he was chairman of the AIEE branch. Mr. Lo Giudice is a member of the SMPE, IRE, and Eta Kappa Nu.

HELEN M. STOTE
Editor

Helen M. Stote was born in Colorado Springs, Colorado. She received the B.A. degree from Stanford University and the M.A. degree from the University of Wisconsin. Before coming to the SMPE as Editor, Miss Stote was Publications Manager of the Institute of Radio Engineers.

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PHOTOMETRIC CALIBRATION OF LENSES

R. KINGSLAKE*

PREFACE

During the past few years there has been a rapidly growing need for a more accurate expression of the photographic speed of a lens than is afforded by the simple *f*-number ratio.

The density of a photographic image depends on (*a*) the brightness of the subject, (*b*) the effective speed of the lens, (*c*) the speed of the film, and (*d*) the exposure time. In modern motion picture photography, all these factors except (*b*) are controlled and known to within a few per cent, but the supposed speed of the lens may be in error by as much as 60 or 70 per cent. This is caused by light lost by surface reflections or by direct absorption in the lens, and to incorrect marking of the *f*-number scale.

For this reason the SMPE Standards Committee has recently set up a Subcommittee on Lens Calibration to study the whole subject and to recommend a standard procedure for measuring the effective photographic speed of a lens. The Subcommittee will also attempt to standardize a new system of speed markings which eventually will replace entirely the *f*-number markings that have heretofore been the only indication of lens speed.

The urgency of this problem is borne out by the fact that since 1941 no less than five papers have appeared in the SMPE *Journal* dealing with lens calibration, and three more similar papers are being published in the present issue. The new Subcommittee contains seven members from the West Coast, to represent the Hollywood interest, and seven members from manufacturing firms in the East and Middle West and from the National Bureau of Standards.

* *Chairman*, Lens Calibration Subcommittee.

COMPENSATION OF THE APERTURE RATIO MARKINGS OF A PHOTOGRAPHIC LENS FOR ABSORPTION, REFLECTION, AND VIGNETTING LOSSES*

IRVINE C. GARDNER**

Summary.—*At present the diaphragm markings of a photographic lens are based entirely upon geometrical considerations and do not take into account the losses of light resulting from absorption, reflection, and scattering. A method of equivalent marking is described in which, for example, the marking 8 does not correspond to the geometrically determined aperture ratio 1:8 but to an opening sufficiently larger to permit the transmission of as much light as would be transmitted by the aperture 1:8 in the absence of any losses due to absorption, reflection, and vignetting. Such a system of apertures may be referred to as equivalent or compensated apertures.*

Two systems of compensation are given, one based upon the illumination at the center of the field and the other based upon the average illumination over the entire field thus taking vignetting into account. A relatively simple photometric procedure for determining either of the two systems of compensated graduation is described. For use during a transition period a system of markings is described which will permit exposures to be determined either with light losses compensated or by the present method without compensation. Except for the change of markings on a lens no other instrumental changes are required to apply the new system of exposure determination.

I. INTRODUCTION

Photography is both an art and a technique. Until a few years ago the technique was largely empirical, each photographer's practice being based on his own experience with his own particular equipment. Now, however, the principles underlying photographic technique are so well known and quantitative relations are so precisely established that photographic engineering may be said to have become an applied science. The possibility of saving large sums of money and at the same time securing greater uniformity of results by greater precision in the exposing and processing of the very large quantity of film used for motion picture photography has constituted

* Presented, Apr. 24, 1947, at the SMPE Convention in Chicago.

** National Bureau of Standards, Washington, D. C.

an economic urge in favor of this transformation. The development of the modern photoelectric exposure meter and the more general dissemination of quantitative information regarding the properties of emulsions have made it possible not only for the professional but also for the skilled amateur to control his photographic work in a scientific manner.

With this progress a demand has arisen for a more scientific method of marking the diaphragm openings of a lens. The method now in general use is based entirely upon the diameter of the entrance pupil and the equivalent focal length. It gives no consideration to the loss of effective light which arises because of absorption in the glasses of which the lens elements are made or because of reflection and scattering at the surfaces. Photographic objectives in common use may have from 4 to 10 glass-air surfaces. The transmissions of such lenses may range from 50 to 80 per cent if uncoated and may be as high as 95 per cent if efficient low-reflection coatings are applied to the surfaces. It is evident, therefore, that the effective exposures for different lenses with the iris diaphragm set for the same aperture ratio may vary by a factor of almost 2, an uncertainty which is inconsistent with the precision with which the other factors governing exposure are controlled.

Several methods for calibrating and marking the apertures of a photographic lens which will effect a correction for the varying light losses with different lenses have been proposed. A method is presented which is relatively simple and direct, and by which different laboratories may be expected to arrive at the same system of marking and equivalent values without the interchange of physical standards. The method is extended to apply to lenses when focused for infinity or for any finite distance, and a system for marking the diaphragm scale is suggested.

In order to distinguish between the older and newer systems of marking, the aperture ratio of the older system, based on geometrical measurements only, will be referred to as the *geometrical aperture ratio*. The new aperture ratio, which takes the absorption and reflection losses into consideration will, for present purposes, be designated the *equivalent aperture ratio*. Other terms which might be used are *compensated aperture ratio*, and *t aperture ratio*, the *t* standing for transmission as suggested by Berlant.[1-3] Consideration is also given to the difference in effective exposure of different lenses because of vignetting.

II. METHOD OF CALIBRATION FOR INFINITE OBJECT DISTANCE

In Fig. 1, L represents a photographic lens which receives light from the uniformly illuminated screen CD. In the focal plane there is the plate GH, with the aperture of area A centered at O. Behind this aperture there is a photoelectric cell with receiver R which is large enough to receive all the luminous flux from the screen CD that is transmitted by the photographic lens and the aperture at O. The full lines represent the boundary of the cone of rays proceeding from

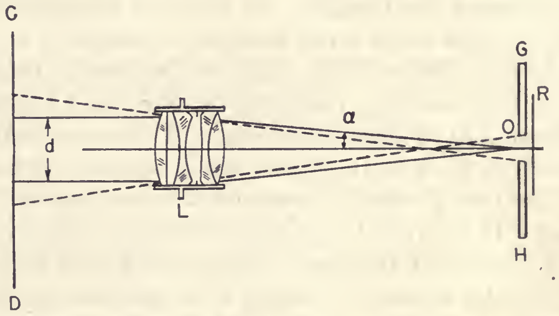

FIG. 1. Arrangement of apparatus for measurement of total luminous flux transmitted through a photographic objective and through an aperture of area A in the focal plane at O. The geometrical aperture ratio is $1:1/(2 \sin \alpha)$.

the screen to the axial point of the focal plane. In the object space the cone degenerates into a cylinder of which the diameter is d. In the image space the half angle of the cone is α, where α is defined by the equation*

$$\sin \alpha = \mathrm{d}/2f. \tag{1}$$

The aperture ratio of the lens for an infinitely distant object is $1:f/d$, where f/d is the f number. It is evident that

$$\text{number} = \frac{1}{2 \sin \alpha}. \tag{2}$$

In Fig. 2, CD represents a uniformly illuminated screen identical with that of Fig. 1. The screen GH with aperture, of area A at O

* There is a temptation to write this equation $\tan \alpha = \mathrm{d}/2f$, but if the lens is suitably corrected for coma, a necessary condition for a photographic objective, Eq (1) is correct.

and photoelectric cell with receiver R, are identical with the similar parts of Fig. 1. At IJ, at a distance e from the plane GH, there is a circular diaphragm of diameter such that the angle α in Fig. 2 equals the corresponding angle of Fig. 1. For the moment it will be assumed that the length e is identical with the equivalent focal length of the photographic objective of Fig. 1. If B is the brightness* of the screen CD and if one assumes a very small area ΔA at O, normal to the axis of the lens and including the axial point, the total luminous flux ΔF received by this area is given by the equation

$$\Delta F = B\ \Delta A \sin^2 \alpha, \tag{3}$$

this equation being exact in the limit as ΔA approaches zero. If it

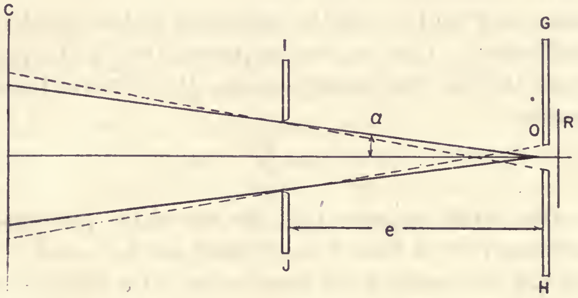

FIG. 2. Arrangement of apparatus for measurement of total luminous flux transmitted through the aperture IJ and through the aperture of area A at O. This flux is equivalent to that transmitted by a lens free from absorption and reflection losses and with the aperture ratio $1:1/(2 \sin \alpha)$.

* Throughout this discussion the terms *illumination* and *brightness* are employed. These terms usually refer to measures of radiant energy evaluated in terms of the luminosity curve and apply strictly only when the energy receptor is the eye or a detector having the same sensitivity curve. Strictly speaking, when discussing photographic applications, one should use terms referring to radiant energy evaluated in terms of the wavelength sensitivity of the photographic emulsion. This paper is concerned chiefly with ratios of two similar measurements of radiant energy and, inasmuch as optical glass, the only absorbing material concerned, shows little selectivity over the range of wavelengths under consideration, all equations are true, to a satisfactory approximation, whether they are considered to apply to light (in the restricted sense) or to radiant energy affected by the photographic sensitivity curve. The justification for the use of the terms applying to light is the greater because there has been no general agreement on terms to be applied to radiant energy evaluated in terms of photographic sensitivity.

is assumed that the actual area at O for which the incident luminous flux is measured has a maximum radius r, such that the ratio r/e does not exceed 0.02, for most photographic purposes the equation

$$F = BA \sin^2 \alpha \tag{4}$$

is sufficiently exact, where F is the total luminous flux incident upon the area A in the focal plane. For the arrangement of Fig. 2 the *geometrical aperture ratio* and the *equivalent aperture ratio* are identical because for the opening IJ there are no reflection or absorption losses.

Referring now to Fig. 1, the total luminous flux F, falling upon the area A, will be given with sufficient exactness by the equation

$$F' = BAk \sin^2 \alpha, \tag{5}$$

k being the transmittance of the lens.

The values of F and F' will be indicated by the photocell if it is suitably calibrated. It is at once apparent that if B, A, and α are held constant for the two measurements, the transmittance is given by the equation

$$k = \frac{F'}{F}. \tag{6}$$

On the other hand, suppose that the iris of the photographic lens or the diaphragm IJ of Fig. 2 is adjusted until $F = F'$. Let α be the value of the half angle of the cone in Fig. 2 for which this equality is obtained. The aperture ratio corresponding to α is $1:(1/2 \sin \alpha_1)$ and the f number is $1/(2 \sin \alpha)$. For this adjustment it follows that the light transmitted by the photographic lens is equal to that which would be transmitted by a lens of zero absorption and with the aperture ratio $1:(1/2 \sin \alpha)$. This method therefore, provides a means for calibrating a lens in such a manner that the absorption losses are compensated.

Table 1 gives the values of α corresponding to values of the aperture ratios that are commonly represented on photographic shutters. To calibrate a lens, therefore, it is necessary only to have a series of diaphragms which, for the length e, will correspond to the different required values of α. A photocell reading is taken with the arrangement of Fig. 2, after which the photographic lens is substituted for the diaphragm and the iris adjusted until the same reading is obtained. This setting corresponds to the given geometrical aperture ratio and zero absorption. If, on the other hand, one wishes to determine the equivalent aperture ratio corresponding to the maximum indicated geometrical aperture ratio, it is necessary to secure

the balance between measurements of Figs. 1 and 2 by adjusting the diameter of aperture IJ in Fig. 2.

TABLE 1

Half Angles α Corresponding to Standard Aperture Ratios

Aperture Ratio	α Degrees	Aperture Ratio	α Degrees
$1:1.4_1$	20.77	$1:11.3_1$	2.53
$1:2.0_0$	14.48	$1:16.0_0$	1.79
$1:2.8_3$	10.18	$1:22.6_3$	1.27
$1:4.0_0$	7.18	$1:32.0_0$	0.896
$1:5.6_6$	5.07	$1:45.2_5$	0.633
$1:8.0_0$	3.58	$1:64.0_0$	0.447

Some of the details and necessary precautions can now be profitably considered. It is not necessary that the length e of Fig. 2 be exactly equal to the focal length of the lens being tested provided that the correct ratio is maintained between e and the diameter of the aperture. It is desirable that e be approximately equal (within 5 per cent is satisfactory) in order that the approximation introduced by the finite area A shall not differ greatly for the two measurements. The area A must be definitely limited and, when the lens is used, it should be located accurately in the focal plane. A suitable way to achieve this is by the use of a metal plate in the focal plane with a circular aperture of the desired area and a photocell back of the aperture with a receiver large enough to receive all the light that passes through the opening. Such a plate is indicated GH in Figs. 1 and 2. The dotted lines in Figs. 1 and 2 indicate the portion of the screen CD that contributes to the illumination at O. It is evident that the contributing areas for the lens and for the aperture will be smaller and more nearly identical if the screen CD be brought close to the lens or diaphragm, respectively.

It is, therefore, recommended that the screen CD be placed immediately in front of the lens and illuminated by transmitted light. Uniform brightness of the smaller area thus utilized is more easily obtained, and deficiencies in uniformity of illumination become less important as the areas utilized during the two measurements become more nearly identical. It is, of course, essential that the brightness of the screen have the same value for the measurement with the diaphragm and with the lens. It is also assumed that all parts of the screen CD contributing to either measurement obey Lambert's law.

In other words, a collimated beam or a surface giving specular reflection should not be used.

There are variations of the experiment that suggest themselves. For the evenly illuminated screen *CD*, an integrating sphere may be substituted. Furthermore, the directions of the light may be reversed with the source at *O* and the receiver at *CD*. In this latter case, if *CD* is not replaced by an integrating sphere, the receiver of the light-sensitive element must be large enough to receive all the luminous flux and it must be uniformly sensitive over the entire area. This requirement can be most easily met if the receiver is placed near the lens *L* or aperture *IJ* as the required size is then greatly reduced.

Strictly speaking, the spectral quality of the light proceeding from the source *CD* when the measurements are made should be identical with that reflected from the object to be photographed, and the spectral sensitivity of the photocell should be identical with that of the emulsion to be used. When one considers the great variations usually present in the spectral quality of the light proceeding to a lens from an object to be photographed, it is evident that it is not practicable to fulfill this condition. Fortunately the absorption of a photographic lens is not particularly selective for different parts of the spectrum, and the values of *k* for a given lens will not differ greatly as the spectral distribution of the light illuminating the screen *CD* is changed. However, for precise work, standardization is desirable and it is accordingly suggested that tungsten lamps operating at a color temperature of 2360 K be used in conjunction with Wratten No. 79 filters. This gives light having a color temperature approximately that of the noon sun (5400 K). The use of a controlled source facilitates intercomparison between measurements at different laboratories. Even in the absence of such a standardized source, if the screen *CD* is illuminated by tungsten lamps operating at normal voltage and if the photocell has a special sensitivity similar to that of the commercial exposure meter, the use of the equivalent aperture ratios, measured by the method of this presentation, will be much more precise and accurate than the use of the geometrical aperture ratios.

III. SUGGESTED METHOD OF INDICATING THE EQUIVALENT APERTURE RATIOS

According to the current method of determining aperture ratio, the diaphragm markings on the lenses will not yield consistent

exposures from lens to lens. Either the speed ratings of the emulsions or the computing tables on the exposure meters, or both, may be considered as adjusted to give the correct exposure for some average value of k_0 typical of photographic objectives. For a lens having a value of k_0 smaller than this average value, the result will be underexposure and for a lens having a higher value (for example, a coated lens) the result will be overexposure. If this assumed value of k_0 were known, it would be possible to alter the speed rating of the emulsions to give correct exposure with lenses graduated to read equivalent aperture ratios. To illustrate, if it were known that the value of k_0 is 0.76 for the average lens[4] is the basis on which the computation tables of a certain make of exposure meter rests, the speed rating of a photographic emulsion for use with the equivalent aperture ratios should be increased by the factor 1/0.76. Once this adjustment of speed ratings has been made, exposures should be self-consistent for all lenses graduated in terms of the equivalent aperture ratio.

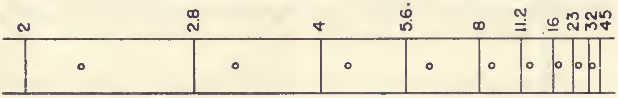

FIG. 3. The aperture scale of a typical lens with the geometric aperture ratios indicated by the graduations and numbers in the conventional manner. Dots (which preferably are in red) indicate the settings for the equivalent aperture ratios. To illustrate, the dot between the graduations 5.6 and 8 corresponds to the equivalent aperture 1:8.

Fig. 3 shows the diaphragm markings of a lens developed into a linear scale. Between each pair of graduations there is a dot. The indicated graduations with numbers correspond to the geometrical aperture ratios as now marked on photographic lenses. The dots correspond to the equivalent aperture ratios, each lot representing the equivalent aperture ratio of the same value as the next smaller geometric aperture ratio. To illustrate, the dot between 2.8 and 4 corresponds to the equivalent aperture ratio 1:4 and similarly the dot between 5.6 and 8 corresponds to the equivalent ratio 1:8. Such dots in red have been used at times on lenses for the Leica camera.*

This method of marking may not be entirely unambiguous as there is a possibility of allocating the dot to the incorrect one of the two

* Paul C. Foote, of Bell and Howell Company, has mentioned this type of marking and has made photographs available of a Leica lens so graduated.

adjacent stop numbers. Consequently the marking shown in Fig. 4 is suggested. In this case a line, preferably red, is drawn connecting the setting for the equivalent aperture ratio to the corresponding geometrical aperture ratio graduation. The length of this line indicates the extent to which a lens aperture must be opened beyond a given *geometric aperture ratio* to compensate for the loss of light resulting from reflection and absorption. Having a lens doubly marked in this manner is certainly an advantage during a period of transition when one is changing from the regular use of one set of markings to the other. In addition to marking the lenses, the only change required is the publication of a new set of speed ratings. During the transition period the manufacturers might

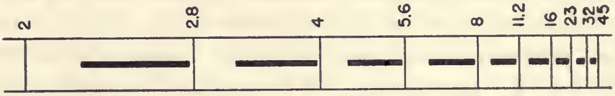

FIG. 4. A preferred system of marking the equivalent aperture ratios in which a line (preferably red) connects the setting for a given equivalent aperture ratio with the geometrical aperture ratio having the same numerical value.

well give two sets of speed ratings in their tables, one in black for use with the geometrical aperture ratios, and one in red for use with the equivalent aperture ratios. Even after the use of the equivalent aperture ratios has become general it might well be desirable to retain the double system of marking on photographic lenses because the geometrical aperture ratios apply more precisely to the depth of focus scales with which many cameras are now provided.

IV. EFFECT OF VIGNETTING

The measurements of Section II have been concerned only with the illumination on the axis of the lens. In Fig. 2, if the aperture O and receiver R are displaced the distance $e \tan \beta$ in a direction normal to the axis of the diaphragm, as shown in Fig. 5 one obtains a measure of the flux corresponding to an image point at an angular displacement from the axis. This will be less than the axial value because of the operation of the "cosine fourth-power law", which is a statement that the illumination in the field of a photographic lens varies as the fourth power of the cosine of the angular distance from the center of the field provided that the diameters of all elements of the lens system are so great that the iris of the lens is the only part of the system that restricts the cone of transmitted rays.

Although this last restriction is seldom fulfilled over the entire field of a lens, it should be noted that, even when this condition is complied with, the cosine fourth-power law is an approximate rather than an exact statement.

The ratio of the illumination at the off-axis position to the axial value gives a measure of the decrease of illumination as the image point moves from the center of the field outward. Let F_β and F_O be the fluxes measured, as shown in Fig. 2 and 5, respectively. Then the ratio F_β/F_O gives the ratio of the exposures β degrees from the axis and on the axis for an ideal lens with no absorption and no vignetting.*

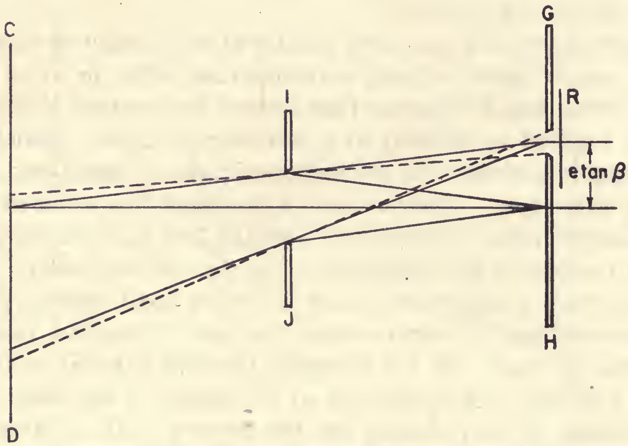

FIG. 5. Arrangement of apparatus for measuring the total flux transmitted through the aperture IJ and through the aperture of area A displaced from the axial position. The measurements made with arrangements indicated in Figs. 2 and 5 give a measurement of the decrease of illumination for points off the axis when there is no vignetting.

The ratio F_β/F_O will approximately equal $\cos^4 \beta$.

Similarly, for the arrangement of Fig. 1, the aperture O and the receiver R may be displaced through the distance $f \tan \beta$ and a

* The term "vignetting" is ambiguous unless defined. It may reasonably be applied to include all the decrease of illumination that arises at an off-axis point in the image plane of a photographic objective, or the term may be used to apply only to the decrease of illumination which arises because of restrictive action of parts of the lens mount or lens elements and which is in excess of that necessarily occurring with an ideal lens. Following the custom of several writers, the second application is used in this discussion. In accordance with this interpretation, there is no vignetting for the system of Fig. 5.

measurement of the illumination made. It will be assumed that the iris is set for an equivalent aperture ratio the same as that for the measurements of Figs. 2 and 5. We now have four readings, F'_O, the axial value for the arrangement of Fig. 1; F'_β, the reading for the arrangement of Fig. 1 with the measurement made β degrees from the axis; and F_O and F_β. Since the equivalent aperture ratios are assumed to be the same in all cases, $F'_O = F_O$. The ratio F'_β/F_β gives a measure of the vignetting, *i. e.*, the falling off in illumination beyond that attributable to an ideal lens.* However, the ratio F'_β/F'_O is the more useful ratio to the lens user because it gives directly the ratio of the exposure obtained at a point β degrees from the axis to that obtained on the axis.

Different types of lenses differ greatly in the amount of vignetting. A lens system which is long in comparison with its focal length requires much larger elements than a short lens system if vignetting is to be avoided or reduced to a satisfactory value. Sometimes a lens system is such that the aberrations for the marginal parts of the field are excessive. Such a fault is rendered less apparent when there is considerable vignetting because the lens is, in effect, stopped down at the edge of the field much more than at the center. Excessive vignetting is sometimes found in folding hand cameras because the manufacturer, in order to make the camera compact, makes the lens elements small. If, for example, the lens is rated as $f/2$, this relative aperture may apply only at the center of the field, the exposure falling off very sharply for the corners of the picture. For such a lens, the vignetting rapidly becomes less as the lens is stopped down and such an arrangement does not necessarily represent an undesirable compromise. The user has a compact camera without excessive vignetting for the aperture ratios that are usually used with modern rapid film and at the same time has high speed, at least for the central part of the picture, for the occasions when it is required. However, when exposures are made on color film with the

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* This is not strictly true because the illumination resulting from the aperture of Fig. 2 does not fall off exactly as the fourth power of the cosine. The diaphragm, however, represents a convenient standard that can be reproduced without difficulty at different laboratories and it follows the cosine fourth-power law as closely as do most lenses in common use. The approximation is better for the smaller aperture and for points near the axis. To illustrate, for points distant 40 deg from the axis the departures are 7.6, 1.8, and 0.4 per cent for the aperture ratios 1:2, 1:4, and 1:8, respectively.

maximum aperture, such vignetting, because of the generally reduced latitude of color film, may be sufficient to detract from the effectiveness of the picture.

V. A SYSTEM OF STOP CALIBRATION WHICH GIVES WEIGHT TO VIGNETTING

The method of stop calibration of Section II compensates for the different transmittances of different photographic objectives and ensures equivalent exposures at the center of the image field for different lenses when used at the same equivalent aperture ratios. However, it does not distinguish between the behaviors of different

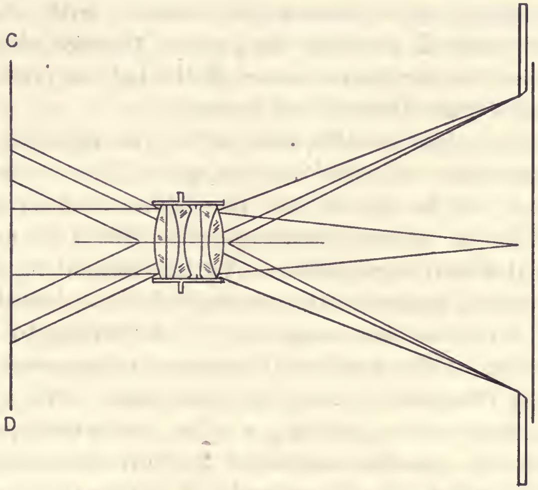

FIG. 6. The aperture in the plate *GH* includes the entire field of view utilized when the lens is mounted for use in a camera. The measurement of luminous flux obtained under this condition is characteristic of the average illumination over the entire field instead of the illumination at the center of the field as obtained by the arrangement of Fig. 1.

lenses which arise because of the differences in vignetting. In Fig. 6 the arrangement is the same as for Fig. 1 except that instead of measuring the illumination of a small area near the axis one measures the total flux received by an area in the focal plane identical with the picture frame. Similarly for the comparative measurement with an aperture only, the arrangement of Fig. 2 is modified to give a measurement of the flux received by the entire field. The equivalent aperture ratios, as before, are considered equal when the two flux measurements are equal. If *e* of Fig. 2 and *f* of Fig. 6 are not equal,

the angular subtenses of the two field stops at the center of the diaphragm and exit pupil of lenses must be equal when the two measurements of flux are made. For photographic purposes the agreement will be satisfactory provided that the two field apertures are identical and the values of *e* and *f* do not differ by more than one per cent.

For a motion picture camera or a miniature camera the field aperture required is small and it is generally not too difficult to make the measure as outlined. If the picture frame is large it may be desirable to reverse the direction of travel of the light, using an integrating sphere to illuminate the picture frame. The total flux is then measured by a photoelectric element with receiver large enough to receive all the light that comes through the lens. By this reversal of the direction of travel of the light, a photocell with a receiver smaller than otherwise can be used.

If the iris of a lens is calibrated by the two methods, measuring central illumination only and measuring the flux received by the entire field, it will be found that the calibrations, in general, are different. This is understandable because the two methods are based upon different assumptions. In the method first described, a given equivalent aperture ratio corresponds to a definite illumination at the center of the image field. According to the second method the use of the equivalent aperture ratio corresponds to a given average illumination over the entire field. For a lens which has a large amount of vignetting a given geometric aperture ratio will correspond to a smaller equivalent aperture ratio than for a lens with less vignetting. Both methods of calibration have advantages, and it is probable that the different standardizing groups interested in photographic procedure should consider carefully the two methods and make recommendations governing their use.

VI. CALIBRATIONS OF STOP FOR FINITE OBJECT DISTANCES

In all the foregoing discussion it has been tacitly assumed that the object to be photographed is at an "infinite" distance and that the image consequently will lie in the focal plane of the lens. This is the basis on which the values of the geometric aperture ratio are engraved on the lens mounts and it is an entirely satisfactory procedure for a large amount of photographic work. If, for example, the object instead of being at an "infinite" distance is only ten focal lengths away, the distance from lens to focal plane is only increased by 10 per cent of the equivalent focal, length, and for many

applications the error in exposure resulting from using the values corresponding to the image in the focal plane will not be excessive.

Lenses for copying purposes and some other types of lenses are habitually used with the object distant only a few focal lengths from the lens and in such instances it is highly desirable that the aperture ratios be marked for one or more selected object distances approximating those which actually will be employed in practice. The method of stop calibration can be readily extended to apply to this problem.

Suppose, for example, that the selected object distance is $2f$, corresponding to the use of the lens for one-to-one copying. Referring to Fig. 1, the plate *GH* bearing the aperture *O* will be moved back from the lens to the image plane corresponding to one-to-one copying. Referring to Fig. 2, the plane *GH* will be separated from the diaphragm by approximately the same distance as for the lens. For this particular case, the separation would be twice the equivalent focal length of the lens. With this new spacing the diameter of the aperture *IJ* should be determined so that sin α has a value corresponding to a selected aperture ratio as given in Table 1. Measurements are now made as before, the diaphragm setting of the lens being altered until the two flux readings are the same. When equality is obtained, the equivalent aperture ratio of the lens, for the one-to-one ratio, is equal to the geometrical aperture ratio of the diaphragm.

If the iris markings are calibrated in this manner the lens will give the same exposure for a given equivalent aperture ratio and one-to-one copying as does the same lens or any other lens with the calibration for infinite distances when used on a distant object. For a finite distance the question again arises as to whether the calibration should be similar to that of Section II, with exposure at the center of the field as the criterion, or the method of Section IV in which the criterion is average exposure over the entire field.

VII. ADVANTAGES OF THE PROPOSED METHOD OF LENS APERTURE CALIBRATION AND SYSTEM OF LENS MARKING

In the foregoing text, reference has been made to several papers dealing with this subject which have been published. The method of calibration and marking herein proposed offers advantages not possessed by any one of the previously suggested methods, as follows:

1. The standard aperture to which reference is made is an aperture of known diameter in a metal plate and therefore can be readily and independently produced by any laboratory. This

facilitates the maintenance of consistent systems of graduation by different laboratories.

2. Each calibration is essentially a substitution method in which the two values of flux to be measured are of approximately the same value. This largely eliminates errors arising from the nonlinearity of response of the photometric apparatus and eliminates the need for carefully calibrated filters.

3. No condenser or collimator system is used. Hence the method does not involve the assumption that the distribution of energy in a collimated beam is uniform.

4. A method of application is proposed which requires no modification of present models of exposure meters. New film-speed tables are required but presumably the data already in the possession of manufacturers of exposure meters will be sufficient for the preparation of these tables.

5. A system of lens marking is proposed which permits exposure to be determined either by the conventional or new method.

6. An extension of the method of calibration has been given which permits lenses to be calibrated for object distances other than infinity.

7. Calibrated value may be based on brightness of image at the center of the field or average brightness of image over all the field, as may be considered preferable.

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[1] BERLANT, E.: "A System of Lens Stop Calibration by Transmission", *J. Soc. Mot. Pict. Eng.*, **46**, 1 (Jan. 1946), pp. 17–25.

[2] DAILY, C. R.: "A Lens Calibrating System", *J. Soc. Mot. Pict. Eng.*, **46**, 5 (May 1946), pp. 343–356.

[3] MURRAY, A. E.: "The Photometric Calibration of Lens Apertures", *J. Soc. Mot. Pict. Eng.*, **47**, 2 (Aug. 1946), pp. 142–151.

[4] GOODWIN, W. N., JR.: "The Photronic Photographic Exposure Meter", *J. Soc. Mot. Pict. Eng.*, **20**, 4 (Apr. 1933), pp. 95–118.

DISCUSSION

CHAIRMAN LORANCE: I have a question that I would like to ask Mr. Gardner. Is there a real necessity for keeping the opening in your method at approximately the focal distance or is that a convenience?

MR. I. C. GARDNER: If the screen that is furnishing your light were absolutely uniformly illuminated and large enough, there would be no need for it, but by doing that you are using approximately the same portion of the screen for both methods.

MR. F. G. BACK: I should like to say that in this method there is no problem of focus. After the meeting I would be glad to show any one who is interested how simple it is.

AN INSTRUMENT FOR PHOTOMETRIC CALIBRATION OF LENS IRIS SCALES*

M. G. TOWNSLEY**

Summary.—*An instrument for calibrating iris scales of photographic lenses is described. The iris scales are calibrated in* T *stops based on the photometric transmission parallel to the axis. This follows the procedure proposed by Daily.*[1] *The new instrument employs measuring and comparison of optical paths which receive alternate light pulses from a single incandescent source. Calibrated attenuation is provided in the comparison beam so that the two systems may be balanced to give a null output from the photomultiplier cell which is used as a null detector. The null-balance principle makes the unit extremely stable and the sensitivity is sufficient to make accurate measurements on iris openings as small as 0.031 in., which corresponds to 1 in.* T 32. *Data are given on transmission of several lens types, and on the accuracy of the instrument, and a proposal is made for changing over to the new system.*

There is growing interest in the photometric calibration of photographic lens iris scales. Studio (motion picture) photography and amateur color film are placing an increasing premium on accuracy of exposure. Reflection-reducing coatings have increased the variation from lens to lens in the exposure produced by any given *f* stop because the upper limit of lens transmission has been raised to approximately 95 per cent from the old maximum of perhaps 85 per cent; so that it is now possible to have nearly a two-to-one ratio between the exposures made with two lenses having the same geometrical *f* stop. There seems no alternative to the eventual adoption of a photometric system of calibration.

Several methods of calibrating lens iris scales on a photometric basis have been proposed from time to time. Of these, the proposal advanced by Daily[1] seems the most logical and has the advantage that it is reproducible in any laboratory without interchange of any master standards. This method involves the comparison of the light flux transmitted from a collimated beam entering a fixed circular opening with the light flux transmitted from the same beam by the

* Presented Apr. 24, 1947, at the SMPE Convention in Chicago.
** Bell and Howell Co., Chicago, Ill.

lens under test. The T stop corresponding to any iris opening is the quotient of the focal length of the lens divided by the diameter of the fixed circular opening having the same light transmission. The T-stop system proposed by Daily will then have the same significance as the present f-stop system except that the transmittance will be corrected for and will employ the same series of numbers to designate openings. A lens of a given T stop and no transmission loss in the lens would have a physical iris (strictly, entrance pupil) opening equal to the comparison opening and, therefore, would have f stop equal to the T stop.

If the transmittance is k, we have the following relationship between T and f stops:

$$f = L/d$$

$$T = L/D$$

where L is the focal length
d is the entrance pupil diameter
D is the comparison stop diameter

$$(d/D)^2 = k$$

$$T = L/d\sqrt{k} \qquad T = f/\sqrt{k} \qquad f = T\sqrt{k}.$$

Hence, if k becomes equal to 1 (100 per cent transmittance), the T stop and the f stop will be the same. In general, k will be less than 1.0 and the opening will be larger for a given T stop than for an f stop having the same number, and will transmit more light by a factor $1/k$.

Gardner[2]* proposes to select a lower value of k so that lenses calibrated in the T system will correspond more closely to present lenses and will result in a minimum of change in present exposure meters and depth of field tables. This seems unnecessary. The exposure correction may be easily taken into account by using a simple multiplying factor $1/k$ to correct the film-speed value to be used. For the Weston exposure meter, the factor is implicitly given in a paper by Goodwin[3] as 1/0.76, since the value 0.76 was introduced into the exposure-meter equation as a correction factor for lens losses. Future exposure meters could use $k = 1$ in the equation $t = kT^2/B_0s$.

The correction for depth of field tables is of even less importance because of the uncertainty and lack of general agreement on the circle

* AUTHOR'S NOTE: In the published version of Gardner's paper, this proposal of $K < 1$ is omitted.

of confusion to be used. Existing tables may be used without serious difficulty, or new tables may be based on corrected values of the circle of confusion. In general, the tables will indicate a slightly too great depth of field if existing tables are used with T-stop lenses.

Support for the choice of k equal to 1.0 is shown in Fig. 1. This figure shows a comparison of the marked f stops of a group of 10 lenses with actual T stops. The circular points represent the uncoated lenses in the group, while the squares represent the coated lenses. It will be seen that the coated lenses fall very close to the line $k=1.0$, while the uncoated lenses in general fall well

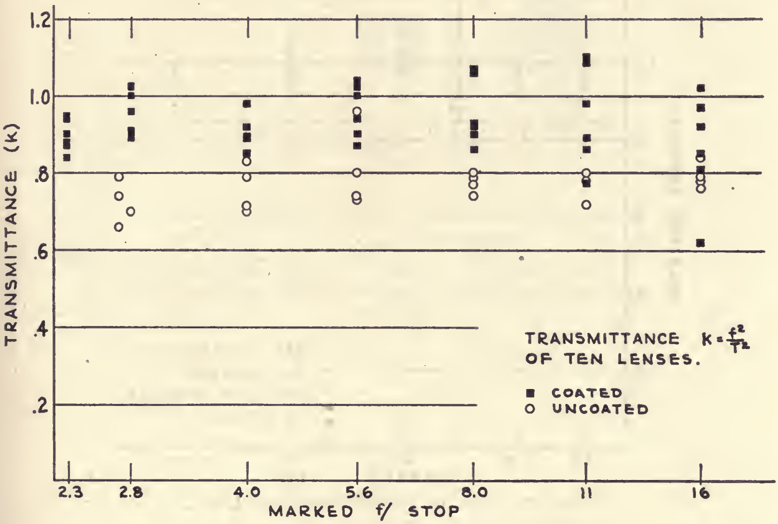

FIG. 1. Transmittance of a group of lenses.

below this line. This means that there are already many lenses in existence, marked in f stops where the value of k is very nearly equal to 1.0, and that properly coated lenses can almost reach this value. It will also be seen that the value of k varies widely, making the choice of any particular value different from 1.0 very difficult.

There seems to be no important reason for showing both the f and T scales on any single lens. Such a dual marking has been used on one German lens which has been examined by the author, and has been described by Gardner from data supplied by the author. The confusion incident to the use of dual markings would far outweigh any possible advantage. It is considered quite important that the

markings be placed at the exact points in the true $\sqrt{2}$ series, even though the figures shown on the lens are rounded, *e. g.*, 11 should be 11.313.

As an illustration of the reproducibility of the basic system of lens calibration proposed by Daily, we may cite a recent experience with the system. An order was placed with an English optical firm for a quantity of lenses which were required to be photometrically calibrated. It was decided that the method proposed by Daily would be employed and that the lenses would be marked in T stops according

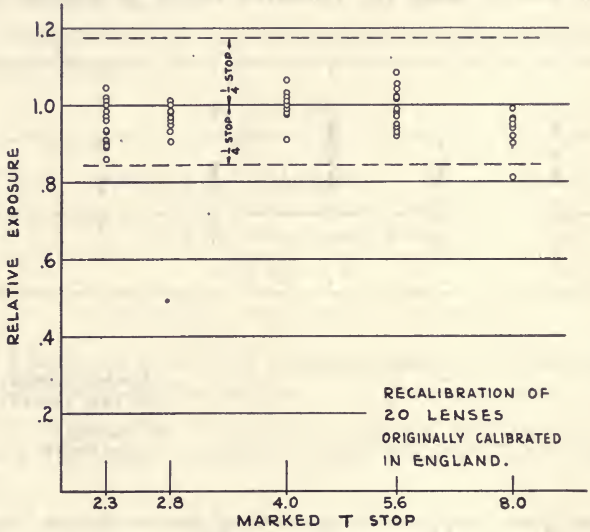

FIG. 2. Test of sysem reproducibility.

to Daily's definition. At the time, Daily's paper had not been published. The present author, from the published abstract of Daily's paper and notes taken during its reading, wrote a description of the method which was forwarded to the English manufacturer. From this description, he was able to construct the basic apparatus (using a different light-measuring system), and furnish the lenses calibrated in T stops.

On receipt of the lenses, they were rechecked in this laboratory and found to be in good agreement with our own measurements. The actual comparison is shown in Fig. 2. The data are plotted as relative exposure *versus* marked T stop, where the relative exposure is the ratio of the actual exposure which would occur to the exposure

computed from the marked T stop. It will be seen from the figure that only one stop in the entire group of 20 lenses falls outside the $^1/_4$-stop limit lines proposed by Berlant.[4]

It is not the primary purpose of the present paper to consider in detail the system to be chosen, although it has seemed worth while to present the personal opinions of the author and his associates as a part of the introduction. The opinions of others are already on the record.[1–7] Rather, it is proposed to describe an instrument which combines a null-balance photoelectric measuring method described by Carpenter the sensitivity of the photomultiplier cell, and the basic

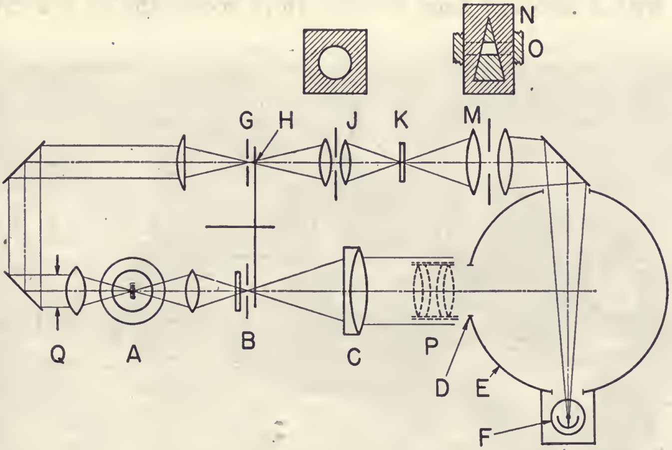

FIG. 3. Schematic optical layout.

method of Daily, into an instrument which is stable, precise, and sufficiently sensitive to calibrate stop openings accurately as small as $^1/_{32}$ in. in diameter. The optical system is shown schematically in Fig. 3. In accordance with Daily, the instrument incorporates a lamphouse A in which a 750-w projection-lamp filament is imaged in a small ($^1/_8$-in. diameter) opening B which forms the source for a large collimating lens C. An opening D in an integrating sphere E faces this lens at a convenient distance. A holder is provided over this opening D into which slides perforated with standard openings may be inserted. Provision is made for mounting the lens P to be calibrated in front of the sphere opening so that all of the light leaving the lens is transmitted into the sphere. An electron-multiplier photocell F is placed in the sphere wall at 90 degrees to the window. So much of the system follows Daily.

From the rear side of the lamp filament, a second light beam is carried by mirrors and condensers to form a second filament image in the same plane as the collimator source image and approximately 6 in. away at *G*. The fan motor which cools the projection lamp has its shaft horizontal and midway between these two images. A chopper wheel *H* is mounted on this shaft to interrupt both beams, and the apertures are phased so that the two beams alternate. The second beam is used as the comparison beam in a manner analogous to that used by Carpenter in the Baird nonrecording densitometer.[8] A lens *J* images the source aperture on an opal glass *K*. This lens is provided with a series of fixed circular stops increasing in $\sqrt{2}$ ratio in

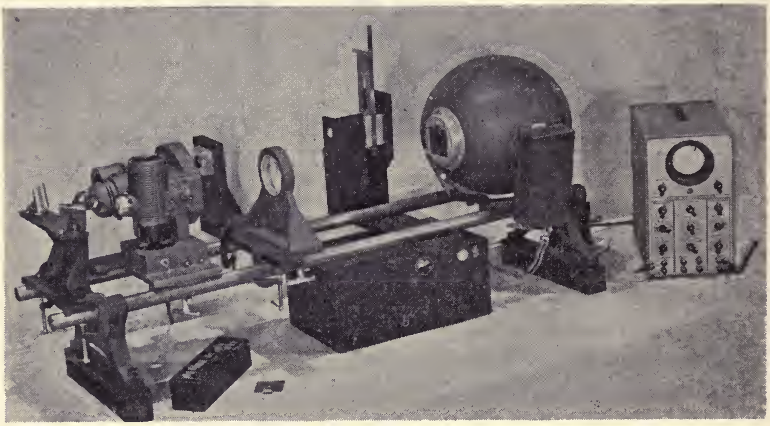

FIG. 4. Completed instrument.

diameter, corresponding to the iris stops from *T* 2 to *T* 32. This lens and the stops serve as a stepped attenuator. A second lens *M* images the opal glass on the photocell, projecting its beam by means of a mirror directly across the sphere. The second lens has a wedge-shaped slit diaphragm *N* sliding across a fixed narrow slit *O* to give continuous attenuation of the light intensity. This slit is calibrated in terms of the equivalent focal lengths of the lenses to be tested. An iris Q in the illuminating portion of the beam serves for initial balancing, and for rebalancing when lamps are changed.

The construction of the instrument in its present form is shown in Fig. 4. The lamphouse is seen at the left end of the optical bench support, with the collimator lens between the lamphouse and the

sphere. At the rear of the lamphouse are the condenser lenses, and the mirrors which furnish the light beam for the comparison track are mounted on the bench on the side away from the operator, with the lens having the circular stops closest to the lamphouse and the lens having the wedge attenuator closest to the sphere. The amplifier is placed where it can be reached for occasional adjustment of the gain control at extremely high or low light levels.

Fig. 5 shows the instrument with a lens in place for direct photometric calibration and marking of its diaphragm ring. The lens is mounted in a separate holder in front of the sphere opening, and a flat steel table and a small scriber point are used to mark the iris points at

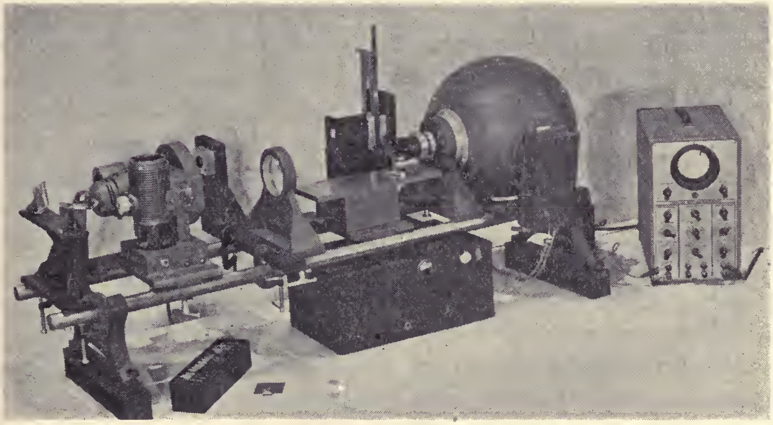

FIG. 5. Completed instrument showing lens in place for calibration.

the various T stops. In use, the focal length is set off on the wedge scale, the T stop is set into the first lens in the comparison beam, the lens to be calibrated is stopped down to bring the null indicator to balance, and the scriber is used to mark the point on the ring. This point is later picked up in the engraving machine and the permanent engraving done from the scribed line.

The double interrupted beams give alternate pulses of light into the sphere, and the calibration beam may be attenuated to match the magnitudes of the two pulses to give zero variation in light intensity on the photocell.

The electrical portion of the instrument is shown schematically in Fig. 6. A Type *931A* photomultiplier cell is used as the sensitive

element. This cell has the *S4* response, which peaks in the blue. When this tube is used with an incandescent lamp, the net effective response peaks at 500 millimicrons, and gives a fairly good compromise. Ideally, as Daily points out, in order to take coating color into account, the response should correspond to panchromatic film. Two cells of different response and appropriate filtering can be made to give a good approximation to this response, but there is no red-sensitive electron-multiplier photocell commercially available; 900 volts direct current are supplied to the voltage divider which furnishes dynode voltages to the cell. This voltage is filtered by the 10-henry choke and the two 1-μf capacitors to reduce 60-cycle hum, and one

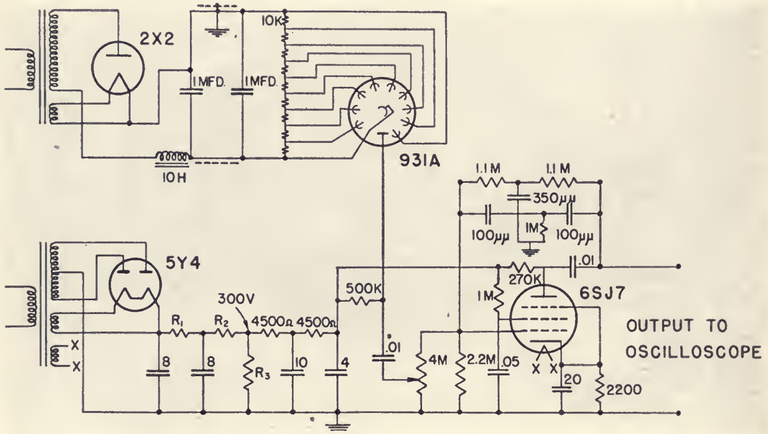

FIG. 6. Schematic circuit of null detector.

of the capacitors is placed within the shield around the photocell to filter out any possible line pickup. Output voltage is fed through a shielded cable to a single-stage amplifier as shown. The voltage supply shown for this amplifier is slightly unconventional because of modifications to suit a conveniently available transformer which was designed to furnish power to several tubes, and had to be equipped with a bleeder and voltage divider to give the voltages required for the present amplifier. The multiplier output is coupled through the 0.01μf-capacitor, and gain control is provided by a 4-megohm potentiometer, the voltage to the grid being determined by the position of the arm on this control. A parallel-*T* feedback loop is used to tune the single stage to pass only the 1080-cycle frequency to which

the chopper wheel is set. This tuning is kept quite sharp to eliminate stray pickup and 60-cycle disturbance so far as possible.

In general the circuit is very similar to that used by Carpenter, with the exception of the use of a pentode (*6SJ7*) for the amplifier tube and the tuning to a different frequency. Instead of the rectifier and tuning eye which Carpenter uses for a null detector, the present unit uses a 3-in. oscilloscope. There are two reasons for this choice. The first reason was the ready availability of the instrument in the laboratory. The second reason, and the one which really controlled the choice is that there is a 120-cycle component in the light from the lamp which cannot be completely filtered out, and which, particularly at very high light levels, modulates the unbalance voltage. If the oscilloscope is swept at 60 cycles, by applying line frequency to the horizontal plates, this 120-cycle modulation appears as a stationary loop on the screen with the unbalance voltage superimposed as modulation on the loop. This very considerably increases the precision with which a null setting can be made.

If the instrument were to be restricted to lower light levels within the sphere by limiting its range or by attenuating the primary beam, it might be possible to omit this refinement and use the tuning eye as a null indicator. It was not considered desirable to employ attenuation in the primary beam because of the necessity of maintaining calibration of the attenuator, and it seemed essential to cover at least the range of diameters from $^1/_{32}$ to 2 in.. When it is realized that this represents a 1-to-30,000 range of light intensity within the sphere the difficulty of maintaining satisfactory sensitivity over this range will be appreciated. Attenuation of the primary beam by a nonselective means which would not change the optical characteristics of the system might be satisfactory for a production-type instrument. Evaporated inconel films as described by Benford might be satisfactory for this purpose, since such films have uniform absorption for all colors of the visible spectrum, and are nonscattering.

Original calibration of the instrument is made by means of a set of fixed, accurately made circular stops ranging in size from 0.0312 to 2 in. by steps having a ratio of 2 in area. These stops are placed in the holder over the sphere window, and the stops in the first lens in the comparison beam are matched to them, point for point, for at least two settings of the wedge diaphragm. The wedge diaphragm is then calibrated for equivalent focal length in the same manner, for at least four combinations of primary and secondary stops. Once

the instrument has been calibrated in this way, it is necessary only to check one or two points occasionally to be sure that the calibration remains correct. The null-balance method eliminates the effects of electrical drift, and only movement of elements or dirt in the optical system can affect the calibration of the beam-attenuating system.

Measurements are made by inserting the lens to be tested in the collimated beam in front of the sphere window at P. If the lens is being originally calibrated, the focal length is set off on the wedge aperture scale, and the desired T-stop value inserted in the comparison beam in the first lens J, the iris of the lens being graduated is closed until the null point is reached, and the point is scribed on the iris ring. This procedure is repeated for each stop to be marked.

If the lens under measurement is being checked for correctness of existing engraving, the corresponding stop is inserted in the comparison beam, the iris is set to the mark, and a balance is secured by varying the wedge aperture. The corresponding equivalent focal length is read from the calibration curve for the wedge, and the T stop is computed from the relation

$$\text{true } T = \frac{\text{indicated } T \times \text{true } L}{\text{indicated } L}$$

We have here the situation where a lens of focal length L has a marked T stop T_1 and hence an equivalent diameter D_1. The calibration beam is therefore set to balance the light transmission of a stop of diameter D_1. But experimentally, we find that the stop marking is in error and shifts the focal-length slide to a new position corresponding to a focal length L_M. This changes the equivalent opening diameter for which the system is balanced to

$$D_M = L_M/T_I$$

but

$$T_M = L/D_M$$

whence

$$L/T_M = L_M/T_I$$

and

$$T_M = T_I L/L_M.$$

The system of T stops proposed by Daily, and followed in this work, requires an accurate knowlege of the equivalent focal length of the lens being calibrated. We are fortunate in having available to us, in our Optical Engineering Department, a focal-length collimator with which all focal length measurements used in this work were made. This collimator consists of a well-corrected lens of 24-in. focal length having a ruled reticle in its focal plane. Rulings on this reticle subtend accurately known angles. The lens to be measured is

set up facing the collimator, a microscope is focused on the image plane, and the lateral spacing between images of the rulings is measured. If the angle subtended by two rulings is θ, and the measured distance between their images is d, the equivalent focal length is found from the equation

$$L = \frac{d}{2 \tan \theta/2}.$$

This method is identical in principle with the one shown by Daily, but is much more convenient and rapid if the collimator is available. The collimator method is given in detail by Hardy and Perrin[9].

Where large numbers of lenses are to be calibrated to commercial standards of accuracy, it is expected that the labor of measuring individual focal lengths can be avoided by using the group average focal length for the entire group providing the group does not show excessive scattering of the individual focal lengths about the average. It is usual experience for all lenses of a given design to group quite closely in focal length, even though the group average may be somewhat different from the nominal or design focal length. This is true even for batches of a given design manufactured at different times. The effect is probably caused by failure of a designer to readjust the design when the focal length happens to differ slightly from the nominal figure after all of the aberrations have been corrected, and by slight further changes caused by fitting the design to existing curves in setting up the tooling for the lens. Once the tooling is fixed, there is little likelihood of the focal length shifting during manufacture except as it is slightly affected by tolerances in index, thickness, and spacing.

The permissible accuracy of the T stop governs the tolerance on the measurement of the equivalent focal length. Where production lenses run within a total tolerance of ± 2 per cent, the batch average may safely be used as a basis for marking the T stops. The batch average may be as much as 8 to 10 per cent above or below the nominal focal length. This will in general introduce an error too great to be tolerated into the T-stop markings if the nominal focal length is used as the basis of calibration.

This point is covered here in some detail to emphasize the necessity for using at least the group average focal length and not using the nominal or marked focal length on which to base the calibration.

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A SIMPLIFIED METHOD FOR PRECISION CALIBRATION OF EFFECTIVE *f* STOPS*

F. G. BACK **

Summary.—*Many methods have been proposed to replace the geometrical* f *ratio by an effective calibration which takes the transmittance of the lens into consideration, but no method proposed so far has been accepted. The author outlines a new method of photoelectric lens calibration using the null method which compares the lens to be calibrated to a standard lens. This standard can be easily reproduced with a very high uniformity of performance. The method has been tested very thoroughly and is now in practical use for lens calibration. The accuracy obtained with this method is far superior to any procedure used so far. Its simplicity enables even an unskilled operator to obtain accurate results combined with a high working speed.*

It is a well-known fact that our present method of designating lens *f* stops by the ratio of the focal length to the diameter of the entrance pupil is not satisfactory. In this age of multisurfaced lens systems, the geometrical *f* ratio is a very unreliable measure for the amount of

* Presented Apr. 24, 1947, at the SMPE Convention in Chicago.

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light reaching the film. It is not necessary to go into the reasons therefor; they have been explained time and again. It is certainly annoying if, relying on the speed calibration of our lens, we find out after processing, that the exposure is incorrect and that the lenses of different focal lengths give different exposures in spite of being set to the same *f* stops. The reason therefor lies in the fact that the geometrical *f* ratio tells us only about the amount of luminous flux entering a lens system while the exposure is determined by the amount of light passing the lens. To avoid an unpleasant surprise of the kind mentioned above, all lenses should be calibrated by transmission; then we shall be assured of proper exposure, according to our meter, regardless of focal length and origin of our lenses.

Many excellent methods have been proposed to measure the actual light transmission of photographic lenses but none of these methods has been accepted generally, because, while scientifically correct, they can be used only by highly skilled operators and require extensive and complicated apparatus. They can, therefore, be used only in lens-manufacturing plants or laboratories where the necessary equipment and personnel are available, but they are beyond the scope of an average motion picture studio, to say nothing of small production units, photographic dealers, and repair shops.

Any new lens-calibration method should take into consideration the vast number of lenses presently in use and not only the lenses to be manufactured in the future. Such a method should, therefore, be so simple to operate that all these groups mentioned above can easily and speedily check and, if necessary, recalibrate the lenses they have on hand.

A procedure is not generally usable if it requires the determination of the exact equivalent focal length for each individual lens, as a prerequisite for the calibration measurements. Also, methods requiring amplifiers, attenuators, chopper wheels, oscilloscopes, or even successive measurements are impracticable, because they entail the danger of objective and subjective measuring errors. To obtain a reliable result by such methods, a great number of measurements for each stop is required and the observational and operating errors have to be eliminated by curve-fitting, partial correlation, and other highly complicated mathematical methods which also are far beyond the reach of the average user of photographic lenses.

In developing our method for light-transmission calibration, we were guided by the facts and requirements mentioned above, We

wanted to simulate as closely as possible actual camera conditions. Our main aim was uniformity of exposure, regardless of focal length or design of lens, easy and exact reproducibility of the measuring setup, and complete independence of the skill of the operator and measuring conditions. The proposed standard may seem arbitrary at first glance, and perhaps does not meet the requirements of a scientifically exact standard of comparison, but the new effective *f* values do not deviate too much from the *f*-stop figures now in use. Any substantial deviation from these *f* values would not only render all meters, depth scales, and other tables based on the present *f* ratio obsolete, but it would cause a great deal of confusion among professional and amateur photographers and cinematographers alike. Especially in the motion picture industry, the *f* stop does not only designate the aperture of the lens but is also used to measure the lighting of the set. Finally we think that the scope of a lens-calibration method should not be confined to motion picture lenses only, but should also include all photographic lenses.

Summarizing the requirements of a lens calibration method as described above, we find the following:

1. The accuracy obtainable should be better than 5 per cent.
2. The instrument should be independent of observational errors.
3. It should be independent of current fluctuations or other operating conditions.
4. The instrument should be simple, with no mechanical or electrical parts such as amplifiers or sensitive meters which can get out of order easily.
5. The apparatus should be reproducible with commercially available material anywhere, anytime; and each piece of apparatus built to specifications should work within 5 per cent limit.
6. The device should be simple to operate so that even an unskilled person should be able to calibrate or measure with a high degree of accuracy.
7. The method and the instrument should be generally usable for all photographic lenses and not only for 35-mm motion picture lenses.

Other methods proposed so far have met some of the requirements but there is no method, to our knowledge, which meets all seven of the requirements listed above.

Requirements 1, 2, and 3 can be obtained by a null method only.

Requirements 4 and 5 can be achieved only with the barrier-layer cell instruments which work without amplifiers.

Requirement 6 can only be obtained by using a comparison standard.

Requirement 7 has not much to do with the method itself, but depends largely on the mechanical design.

So far, each of these principles by itself has been applied previously in other methods, but they have not been combined because there were certain links missing.

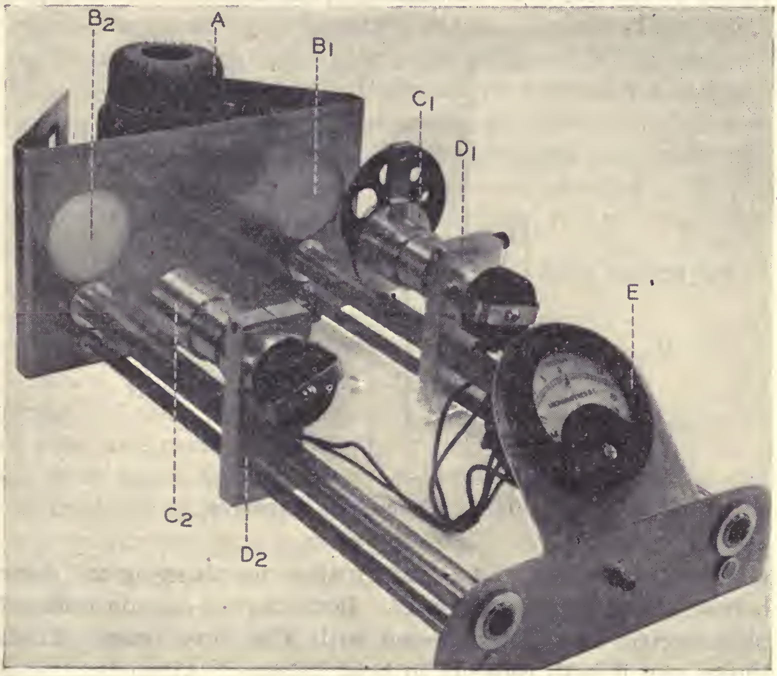
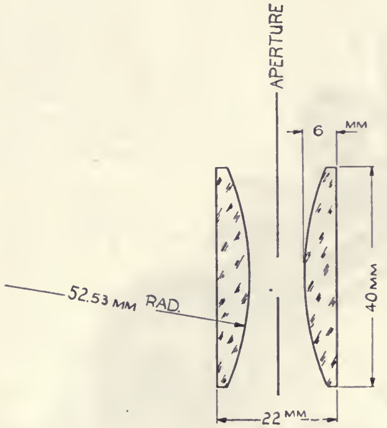


FIG. 1.

The instrument we designed to meet the abovementioned specifications is a very simple and compact one and is illustrated in Fig. 1. The instrument consists of four basic parts: (*1*) light-source assembly; (*2*) variable standard assembly; (*3*) fixed standard and calibrating assembly; and (*4*) balancing meter assembly.

The light source A which is a monoplane 500-w incandescent projection bulb throws two opposite light beams over two condenser systems on two opal-glass disks, B_1 and B_2. The condensers are arranged in a way to give even illumination over both disks. These disks are always equally illuminated independent of voltage drop in the power-supply line and present a balanced light source for the two standards, C_1 and C_2.

Standard C_1 is a variable standard which contains a disk with a number of exact calibrated aperture holes. Standard C_2 is a fixed standard with an f stop of $f/4$. Standard C_2 serves only as a balancing standard before the actual calibration is done and is replaced by the lens to be calibrated. Both standards are mounted on



f	*Aperture Size*
$f/2$	1 in.
$f/2.7$	$^3/_4$ in.
$f/4$	$^1/_2$ in.
$f/8$	$^1/_4$ in.
$f/16$	$^1/_8$ in.

FIG. 2. Comparison Standards.

movable carriers, D_1 and D_2, which allow for changing the distance between light source and lenses. Both carriers contain cells. The photoelectric cells are connected with a sensitive meter E which shows zero if both cells are in light balance. A potentiometer is used to compensate for the small deviations in the symmetrical setup.

We propose as a standard two identical plano-convex lenses made of *BSC-2* glass, placed with their vertexes against each other with the aperture stop in the middle, as indicated in Fig. 2.

We dislike going into mathematical details but those dimensions have the advantage of being inch fractions in so far as aperture holes

are concerned and can be reproduced with commercially available tools. All millimeter measurements given there can be measured with an ordinary micrometer, except for the radius of the lens curvature, which has to be done with a standard spherometer.

Using this suggestion as a basic standard for lens-transmission calibration, a diaphragm hole of one in. represents a geometrical aperture of $f/2$, an aperture diameter of $^1/_2$ in. represents a geometrical aperture of $f/4$, $^1/_4$ in. represents $f/8$. This standard lens has, of course, a certain transmission loss caused by reflection, aberration, and absorption. We do not care how big the percentage of transmission loss is but we shall take this transmission loss caused by the physical properties with this particular standard, as a base for our comparison method. This standard can be reproduced anywhere, at any time, with a high degree of accuracy because *BSC-2* glass is very uniform. Refraction index and dispersion are everywhere held within very close limits. A well-polished surface has always the same reflectivity. There is no coating applied which might cause variations. There are no cemented surfaces introduced which cause a different percentage of absorption, and last, but not least, this particular glass is readily available. This standard has similar light-transmission properties to a large number of commercially available lenses now in use, as for instance, the Eastman Kodak $f/2.7$ series. This presents a great advantage, since many lenses will not have to be recalibrated because their present calibration is very close to the f-stop marking of our standard.

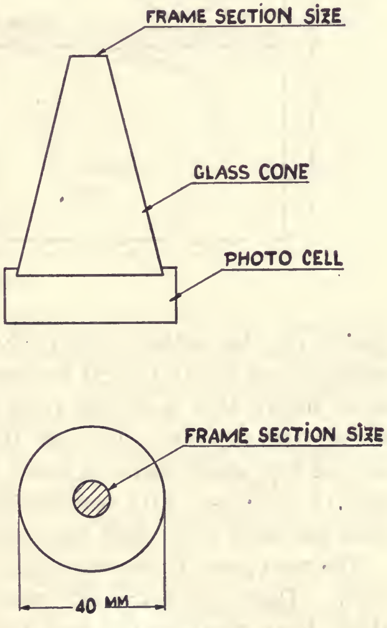


FIG. 3.

As mentioned previously, it is necessary to use self-generating photocells which do not require an amplifier. Since two are needed for the comparison method, both cells should be equal as far as characteristics and sensitivity are concerned. Pairs of equal cells are easily

obtainable; but there is one disadvantage. Since they are equal only as long as the sensitive surfaces are illuminated evenly and over the entire cell, which is 40 mm in diameter (and smaller cells are not available), we had to find a method which distributes the flux of a smaller surface evenly over the entire cell surface. Here, a simple little invention was made consisting of a frustum of a cone, made of *BSC-2* glass, with a base 40 mm in diameter, and a top surface of the area to be measured. This little integrator is silver-

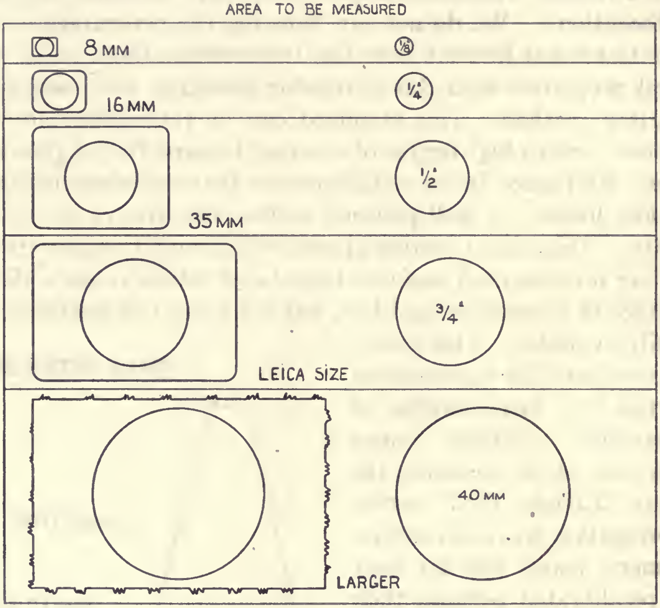


FIG. 4.

plated on the outside, except for the base and top. The base is polished and the top is left fine-ground. (See Fig. 3.) Experiments have shown that a 25-deg cone gives optimum results. By introducing two of these cones into the measuring instruments, illumination of two small surfaces could be compared with a very high degree of accuracy, with commercially available pairs of photoelectric cells and with a standard microammeter.

The next point to be considered is the size of the surface to be measured. There are many differences of opinion on this subject; all of them have their merits and their disadvantages and advantages.

Some authors say we should measure only the center of the field; some like to measure the mean of the entire frame and some of them wish to measure just a fraction of the frame. In order to come to some conclusion and not to be too arbitrary, we made practical tests. Slides were made with different over-all density and different density distribution. Some of them had the same center density, some had the same over-all density, and some of them were unevenly illuminated. These slides were projected in different sequences on a screen and a number of observers gave their opinions on which slides represented slides of equal density. Considerable density variations

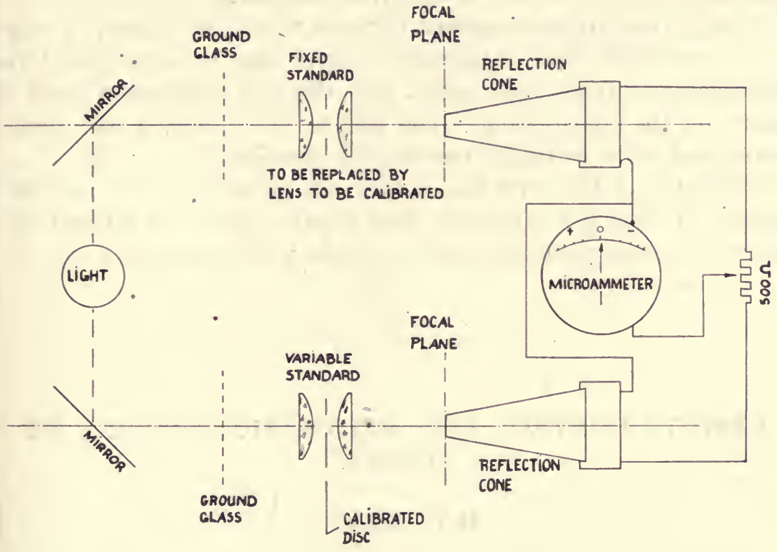


FIG. 5.

in the edges and corners went unnoticed by most of the observers. Differences in center density were not noted very much. Variations in a large central portion of the entire screen were noticed and it was found that there is a definite field, which we call "the center of attention", which consists of a circle with an approximate diameter of 80 per cent of the height of the frame. This diameter is not very critical and here we could arbitrate. Again we choose standard inch fractions and our proposal is illustrated in Fig. 4.

Glass cones were not used for anything larger than Leica size, but only the photoelectric cell itself, since the entire surface is illuminated and there is no integrator required.

Fig. 5 shows a diagram of the entire instrument but does not show the condenser system, which is located between the light source and the deflection mirrors.

The procedure of transmission calibrating a lens is a very simple one. First, the fixed standard C_2 is connected to its carrier D_2 then, the variable standard C_1 which is permanently connected to its carrier D_1 is set to $f/4$. The photocells should be in balance now and the microammeter should show zero reading. If this is not the case, we have to compensate with the potentiometer until the instrument reads zero. Now, everything is balanced and the fixed standard is replaced C_1 by the lens to be calibrated.

Finally, the variable standard C_2 is set to all the different f stops to be measured. The diaphragm control ring is turned until the microammeter reads zero again, and the new calibration mark is drawn on the control ring. The lens to be calibrated will always correspond to the setting of the variable standard C_2.

Calibrating a lens with this device can be done by any unskilled person. It does not take more than about a minute to calibrate ten different f stops on a lens within an accuracy of 5 per cent.

REMOTE CONTROL AND AUTOMATIC FOCUSING OF LENSES*

H. C. SILENT**

Summary.—*A servo-type of mechanism has been devised which automatically will maintain a lens in focus under the guidance of any one of a number of distance-measuring devices, or which may be arranged to replace the Selsyn-type of remote control for focusing a lens. The mechanism requires no special cam or nonlinear element to fit a particular lens, but automatically solves the equation of any lens for which it may be adjusted at the moment. When replacing a Selsyn system this servomechanism has the advantage that it can never get out of step. The system is particularly applicable to motion picture camera lenses in follow-focus work.*

The field of photography has many opportunities for the application of mechanisms for focusing lenses either by remote control or through

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** Formerly Mitchell Camera Corporation, Glendale, California.

the action of specially cut cams or linkages. Frequently in follow shots the focus of the camera lens is varied by means of either direct gearing or Selsyn motors manually operated in accordance with a scale calibrated to the particular lens in use and under the guidance of some form of distance cuing. On the optical bench a special cam fitted to the lens may be used to maintain focus at different distances. Some form of device which would at all times keep a lens in focus on an object as the distance to the object varies has been the purpose of these mechanisms.

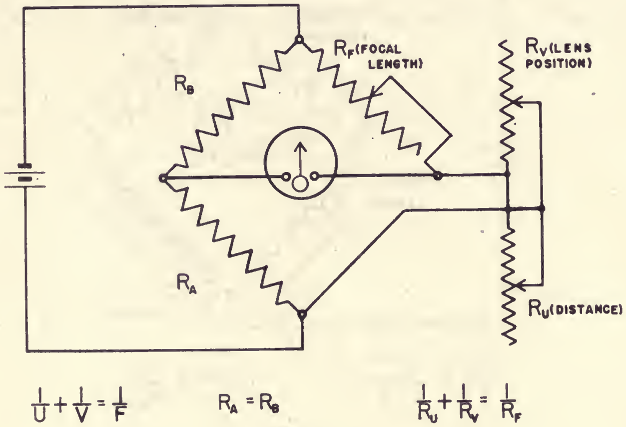


FIG. 1.

This paper describes a mechanism which departs radically from the types now in use, in that it will focus any lens with which it is associated, regardless of focal length, without requiring special scales or cams to work with that lens. The operation is accomplished electrically by means of a servomechanism, may be controlled at a considerable distance from the camera without its accuracy being affected, does not get out of step, and can be made to give an accuracy of setting of the lens position which will meet the most exacting requirements.

The similarity between the lens equation*

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad (1)$$

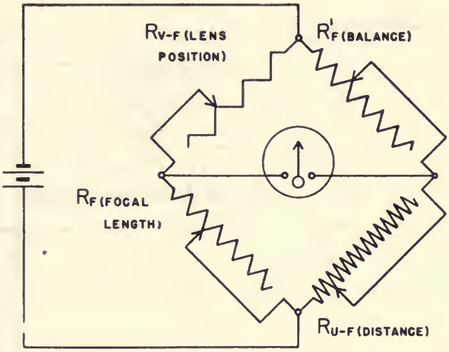
---

* u = lens-to-object distance; v = lens-to-image distance; f = focal length of lens; v/u is defined as the magnification ratio.

and that for two resistances in parallel

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R} \tag{2}$$

has led to the suggestion that, if two resistances be arranged in a Wheatstone-bridge circuit as shown in Fig. 1, and one of these resistances is varied as a function of distance, then the variation of the second to restore the balance of the bridge could be made to focus a lens. In this arrangment R_1 and R_2 bear a scalar relationship to the distances which they represent. For instance, if one inch be



$$\frac{U-F}{F} = \frac{F}{V-F} \qquad \frac{R_{U-F}}{R_F} = \frac{R'_F}{R_{V-F}}$$

$$R = R'$$

FIG. 2.

represented by 100 ohms, the resistance values R_u and R_v (the subscripts corresponding to the optical formula) would be 12,000 and 203.39 ohms, respectively, for a 2-in. lens focused on an object 10 ft distant. With this type of bridge it is at once apparent that only a small percentage change in R_v will be required to restore the balance even though a comparatively large change has been made in R_u. This is true under most practical operating conditions of magnification ratio, and has the effect of limiting the criticalness with which the lens can be focused. Furthermore the ratio of the gearing driving the lens resistance and the distance-measuring resistance must be such that the same scalar relationship exists in both. It will be seen that the adaptation of this form of bridge to lenses of different focal lengths and mounting arrangements involves complexities not present in the form described below.

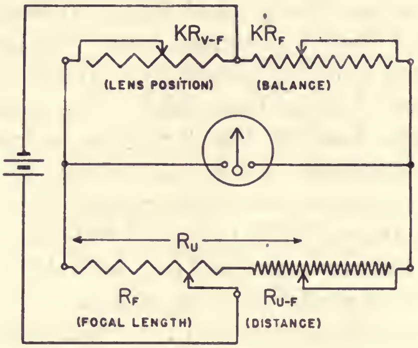
By means of a simple algebraic transformation the lens equation (*1*) can be written in the form

$$\frac{u-f}{f} = \frac{f}{v-f}. \tag{3}$$

Eq (*3*) may be represented by resistances in another form of Wheatstone bridge as shown in Fig. 2, the subscripts identifying the corresponding quantities as follows:

$$\frac{R_{u-f}}{R_f} = \frac{R_f}{R_{v-f}}. \tag{4}$$

As in the previous arrangement each resistance must bear a scalar relationship to the distance which it represents. However, the



$$\frac{U-F}{F} = \frac{KF}{K(V-F)} \qquad \frac{R_{U-F}}{R_F} = \frac{KR_F}{KR_{V-F}}$$

FIG. 3.

equation is explicit in $v-f$, which is the lens displacement from its infinity position. Thus the resistance associated with the lens position in this Wheatstone bridge varies from zero to some finite value, a much larger percentage change than for the arrangement of Fig. 1. Also the full variations of R_{u-f} and R_{v-f} appear in the corresponding arms of the bridge of Fig. 2 without the obscuring factor of the second resistor in parallel. This results in greater criticalness of focus adjustment under most working conditions.

It should be noted at his point that Eq (*3*) is unchanged in its validity when multiplied by the constants k and m as follows:

$$m\,\frac{u-f}{f} = m\,\frac{kf}{k(v-f)}. \tag{5}$$

The constants m and k can be applied correspondingly to (*4*)

without affecting its validity. This permits the use of different scalar factors for the armsof the bridge in an arrangement which will produce the maximum sensitivity. A practical arrangement is indicated in Fig. 3. In the circuit as shown the constant m has been made unity. By so doing, since one arm of the bridge is R_f and its adjacent arm is R_{u-f}, the sum of these arms is R_u and the two arms may be electrically continuous, thereby simplifying the circuit and eliminating the effect of contact resistance at one of the sliders.

The equation applying to the circuit of Fig. 3 is, therefore, as follows:

$$\frac{R_{u-f}}{R_f} = \frac{kR_f}{k(R_{v-f})}. \tag{6}$$

Using a scalar value for R_{u-f} and R_f of 100 ohms per inch gives practical values for these two bridge arms. For any ordinary lens working at less than unity magnification a favorable arrangement is obtained by making k larger than unity. The maximum values of the circuit elements shown in Fig. 3 may be as follows: $R_f = 600$ ohms; $R_{u-f} = 60{,}000$ ohms; $kR_f = 17{,}500$ ohms; $kR_{v-f} = 500$ ohms. Using these values in the circuit shown makes $k = 42.5$ when working with a 2-in. lens adjusted so that $kR_{v-f} = 500$ ohms when the lens is focused at 3 ft. This constant k will vary with different lenses and is not a primary factor in choosing the values of the component resistors. It appears automatically at its proper value in the normal course of adjustment of the circuit. The bridge shown in Fig. 3, when working with a 2-in. lens focused at 10 ft, provides 176 times as much error voltage into a high-impedance galvanometer as the bridge shown in Fig. 1. Accordingly, the sensitivity requirement for the galvanometer (or a servomechanism when employed) is correspondingly reduced by this arrangement over that of Fig. 1. In order to have sufficient sensitivity to focus a lens having a 2-in. focal length to within 0.0005 in. of the exact position for an object at 10 ft requires a sensitivity such that an adjustment will just be initiated when the error voltage produced by the bridge is 0.12 v with 12 v applied to the bridge. A sensitivity of 0.06 v is entirely practicable and results in an even more critical setting of the lens.

While all four of the arms of the bridge used for the device are variable, only two of them, kR_{v-f} and R_{u-f}, the lens-position and distance-measuring resistors, have any particular requirement imposed upon their characteristics, namely, that their variation of resistance shall be linear with respect to their position. Variable

resistors which meet this requirement within 1 per cent are now commercially available and are satisfactory for this service.

Since no variation of resistors R_f and kR_f is required when once set for a particular lens, these resistors may be linear or may be given any other convenient characteristic. Resistor R_f can be fitted conveniently with a scale of focal lengths corresponding to the scalar value of distances applying to resistor R_{u-f}. Ordinarily this calibration can be individually determined and is not at all critical, a variation of 10 per cent introducing negligible error in focusing the lens. Resistor kR_f does not need a calibration scale.

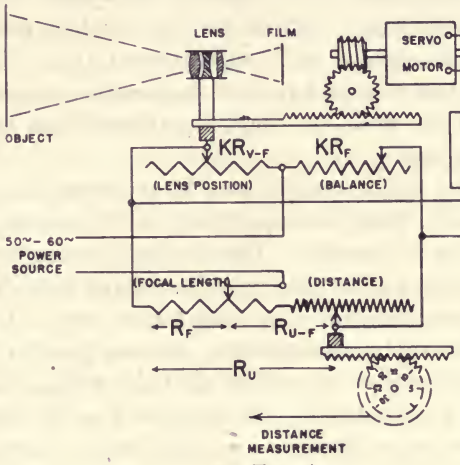


FIG. 4.

The procedure for initially setting the values of resistances in the Wheatstone bridge to operate with any particular lens is very simple and may be performed in the field in a few seconds. Referring to Figs. 3 and 4, the steps are as follows: First, when the lens is mounted on the camera, the coupling to the lens resistor kR_{v-f} is set so that this resistor is on its zero position when the lens is set on its infinity-focus position. Second, the resistor R_f is set at the value corresponding to the focal length of the lens, and is left at this position until another lens is to be used. Third, the distance resistor R_{u-f} is set to the value corresponding to some convenient footage mark on the lens-focusing scale, usually the shortest distance for which it is marked. Fourth, the balancing resistor kR_f is varied until the bridge is in balance when the lens is set at the footage mark chosen in the third step, as indicated by the galvanometer or by the

servomotor coming to rest. The device is now in adjustment and the balancing resistor is left fixed at this position as long as this lens is in use. The correct focus of the lens will always be otained for any particular setting of the distance resistor when the lens is moved to the position which balances the bridge.

The form in which such an electrical focusing device is constructed may vary with the particular application and intended usage. Referring to Fig. 3, the variable resistor kR_{v-f} should be mechanically associated with the lens mount in such manner that focusing from infinity to the closest marked setting varies the resistor from zero to approximately the maximum value, respectively. This variation must be linear with respect to the lens position, but need not have any particular ratio with respect to it. While gear operation between the lens and resistor is possible, a tape or short cable, such as used for radio-set dials, is preferable as backlash or lost motion is minimized.

The other elements of the control may be mounted in a unit conveniently located with respect to operation of the camera, at a distance of several feet if desired. The distance-measuring resistor R_{u-f} may be fitted with a scale calibrated in feet and gear driven from either a distance-measuring tape, cyclometer, or one of the various types of range-finder distance-measuring devices popular in photographic work. For instance, in a dolly shot the distance-measuring resistor R_{u-f} may be adjusted by the movement of the dolly either through a caster running on the floor or a cable fixed to some reference point.

By using a galvanometer to indicate balance and by manually adjusting the lens to keep the galvanometer at zero a follow-focus system is possible which is superior to the present manual follow focus in that a precise indication of the accuracy of the lens setting is obtained and the requirement of a special scale to fit each lens is eliminated. This would be of particular value on locations where battery operation of the device is desirable.

By substituting a servoamplifier and motor drive for the galvanometer, the motor being arranged to focus the lens through gearing as indicated in Fig. 4, focusing will be made entirely automatic and more accurate than can ordinarily be accomplished by hand adjustment. By the use of an alternating voltage on the Wheatstone bridge the servoamplifier is materially simplified and may be given a sensitivity of 0.06 v or greater without entailing any severe

requirements of design. The distance-measuring resistance may be located at any reasonable distance from the rest of the equipment, permitting substitution of the servodrive for Selsyn motors with the attendant advantages of adaptability to different lenses and the elimination of the synchronism requirement. Also, backlash or lost motion in the gear train or flexible shaft between the motor and the lens has no effect since it does not appear in the positioning of the lens resistor kR_{v-f}.

In order to avoid any possible injury to the lens-driving mechanism during the lining-up process when lenses are changed and a readjustment is necessary, a slipping clutch is desirable between the servomotor and the lens. However, this slipping should not be between the lens and its positioning resistor for obvious reasons. With such an arrangement limit switches at the extremes of lens positions become unnecessary.

The values of the circuit elements previously given for Fig. 3 (and which apply equally to Fig. 4) are particularly applicable to lenses of focal lengths from 1 to 6 in. and working at distances from 3 to 50 ft. By minor changes in the values of these elements the range of distances or focal lengths accommodated can be extended as desired. For instance, where lenses covering a large range of focal lengths are to be used at near-unity magnification ratio, some advantages can be obtained by making the constant m (Eq 5) other than unity.

While the device as described applies most easily to lens mounts such as used on motion picture cameras where rotation of the mount causes movement of the entire lens in translation, it may be applied to cameras in which the lens is moved in translation directly.

The mechanical arrangements and electrical requirements are such that great flexibility in the application to a camera is possible. Accurate manual focusing under the guidance of electrical circuits controlled by a distance-measuring device represents probably the simplest application. By the addition of a servomotor, precise focusing from a remote position can be accomplished without the customary errors of backlash and requirements of synchronism. When the distance element of the electrical circuit is associated with a distance-measuring device the servo-operated system becomes a fully automatic camera-lens focusing instrument capable of accurately following changes in distance to an object. A simplified arrangement of the servosystem is adaptable to the remote focusing of a lens of a projector and for many other uses.

Acknowledgment.—The bridge circuits and servocontrol for focusing lenses, as shown in Figs. 2, 3, and 4, were developed for, and during my association with, the Mitchell Camera Corporation. I am indebted to Mr. Donald H. Kelley, formerly of that organization, for the suggestion of a Wheatstone bridge employing resistances in parallel to solve the lens equation, as shown in Fig. 1. Applications have been filed for patents on these circuits and devices for focusing lenses.

DISCUSSION

MR. L. L. RYDER: I think it might be well to add at this point that lens-focusing devices, such as this device described here by Mr. Silent and submitted by Mr. Lorance, are becoming more and more important as we utilize the boom more and more in the shooting of motion pictures and television. There is a definite trend under way now in the Hollywood area of motion picture production to lighten the boom and decrease the amount of equipment and personnel that are carried with the cameras. Devices of this type are accomplishing that end.

MR. G. T. LORANCE: When I was asked to read this paper I was not familiar with its contents. As I read it and tried to understand it, I was really quite surprised by the possibilities of it as a useful tool. I am really pleased that I had the opportunity to see and read the paper.

CHAIRMAN A. SHAPIRO: It appears to be a very unique solution to the problem. I would like to ask Mr. Lorance whether there is a time lag, however small, between the adjustment movement and the actual focusing?

MR. LORANCE: I would guess that while there is a time lag the magnitude of that time lag would be a function of design and could be made so short that no one would ever know it.

CHAIRMAN SHAPIRO: The paper did not have any illustrations to illustrate the mechanism itself. It was intimated that whatever play might exist in gearing would be taken up by the electrical impulses. In finding themselves in balance, would there be a tendency to oscillate?

MR. LORANCE: That again is the function of the design of the servomechanism—the amplifier and servomotor.

Mr. Ryder has indicated that most of the movement of lens is in focusing and is slowly done and there probably would be no particular hazard involved in that.

I think Fig. 4 shows the relationship involved between the servomotor and the lens-position device and the lens-position-measuring resistor. Slippage can occur. The motor can run fast or slow. The resistance is kR_{v-f}. It is related so that when one moves the other does. The motor adjusts itself until it is balanced. That is the point which allows for a slipping clutch in the motor drive, if desirable.

MR. GREEN: Someone expressed the idea that the depth of focus of the lens would more than mask any time lag in the motor. Is that right?

MR. LORANCE: In reading over the paper myself I don't recall any reference to that. My own hunch, and it is purely a hunch, is that it would be very easy to make the mechanism work fast enough. I don't think that you would have to depend on the effect that you mentioned.

MR. GREEN: Can anyone explain how this circuit or proposed mechanism would be adapted to the focusing of a projector lens or are they referring to background projection as used in the studio rather than theater projection?

MR. RYDER: In Hollywood remote-control focusing equipment is used a great deal in background projectors. At Paramount we have a remote-control focusing device on our background projection equipment. The equipment that we use is not of the latest design. When the control dial is turned in one direction as related to the position and brought to rest in the reverse position, it makes focusing very difficult, but the focusing for background projection should by all means be done from the camera side of the background screen. This is a device which should make it practical to focus definitely and definitely work to a given position of the control knob during the focusing on background projection work.

MR. GREEN: The reference then was that it not be adapted to maintain a sharp focus on a theater screen, regardless of the buckle of the film? In other words, to correct the outer focus effect that comes from changing from black and white to color and vice versa?

MR. RYDER: My supposition is that there is no intent that this device would meet that requirement.

MR. LORANCE: I would agree with you.

DR. E. W. KELLOGG: There was reference made to the time lag in adjusting the lens. I am attempting to remark that if the eye were not very tolerant of very brief departures from perfection there wouldn't be any Society of Motion Picture Engineers.

SOME ENGINEERING ASPECTS OF AMATEUR PROJECTION EQUIPMENT FOR THE MASS MARKET*

PERCIVAL H. CASE**

Summary.—*The mass market necessarily is a price market, since only in the low-price brackets are sufficient purchasers found to warrant large volume production.*

Low cost can be achieved while high relative value is maintained, only if the engineering adheres carefully to these fundamentals: (a) elimination of unnecessary features; (b) determination of acceptable minimum levels of performance; (c) provision for attractive external appearance; (d) design of parts for mass production by proper selection of dimensional tolerances, careful tooling to insure such tolerances, and the use of suitable materials; (e) the establishment of economical assembly-line procedure by considering assembly problems from the inception of parts design, providing accurate assembly fixtures, and maintaining adequate process inspection throughout manufacture.

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Before we examine the engineering aspects of amateur projection equipment for the mass market, it is essential that we identify and isolate that market from the total demand for narrow-gauge projection equipment.

The mass market is composed of those who are able, or who are prepared, to spend a minimum sum to possess the equipment necessary to the pursuit of their hobby. It is not composed of persons skilled in the art or who are already earnest enthusiasts. The mass market includes juveniles, or their parents, and beginners who are either persons in modest financial circumstances or in doubt as to whether they will ever be deeply interested, hence only willing to start their adventure into home motion pictures with a small expenditure. No matter how varied their original motives may be, they may all be reduced to one common denominator. They are in search of motion picture entertainment in their homes. Their enjoyment of this hobby is *subjective*. Their satisfaction derives from the entertainment value of the subject matter contained in the films they see projected on the screen, not in pride of possession of a technical instrument.

To the nontechnical mind, quality is a subjective reaction expressed in terms of enjoyment or pleasure. To the nontechnical home motion picture enthusiast "the play's the thing". He is absorbed by the story, he is prepared to laugh at the right places in the comedy, he is interested in the people appearing on the screen—what they do and how they act. He is almost unaware of the medium through which he is receiving his enjoyment or of the technical miracles which make it possible. To him a projector is of acceptable quality if the level of its performance does not introduce annoying distractions to his enjoyment. Beyond that point, mechanical or optical excellence is to him esoteric, unrecognizable, and unappreciated.

When engineers witness a performance on the screen, they are inclined to judge what is seen by a set of standards which are quite technical. Their eyes and ears have been trained to detect and discern minute aberrations. The result is that technical aspects are seen which are not at all evident to the layman who is enjoying the unfolding of the drama and who is concerned primarily with the impressions which he receives from the story. Therefore, it is essential to keep in mind at all times the fundamental difference between the objective definition of quality as insisted upon by the technically trained and the subjective viewpoint held by the great mass of the

general public which evaluates quality solely in terms of the degree of enjoyment which is experienced.

The threshold level of technical quality of performance necessary to meet the subjective approval of persons who comprise the mass market has been carefully and scientifically determined. There has been produced, under the most exacting engineering and manufacturing controls, a projector which delivers the required degree of subjective satisfaction at a low cost that practically every family can enjoy.

The first consideration must be to simplify the design so as to include only such features which have to be incorporated to maintain performance above the determined subjective threshold.

Measured by such a criterion, there are numerous eliminations possible; for example, the framing device. Thirty-five millimeter films have to be framed, they can get out of frame. But why is a frame put on a narrow-gauge projector? A 16- or 8-mm millimeter film cannot be spliced out of frame. If the aperture and the claw are correctly interrelated, and accurately set, no framing adjustment is necessary. It adds to the cost, but not to the user's subjective enjoyment.

A universal motor, capable of operating on either alternating or direct current, is an unnecessary reminder of the days gone by. It is superfluous today when over 99 per cent of homes are supplied with 110-v, 60-cycle a-c. A simple a-c motor can be furnished at a much lower cost than a universal motor and, since it runs at a constant speed, it makes unnecessary the inclusion (at additional cost) of a speed-controlling rheostat. Parenthetically, many amateurs who use a rheostat-controlled projector inadvertently project either too fast or too slow, sometimes with damaging results to film or projection lamps. With a constant-speed motor and a simple two-step pulley, speeds of 16 and 24 frames per sec are assured at will. It is only at these speeds that films should be projected. Therefore, this simple motor is not only an economy but a positive advantage.

Such refinements as stop-on-film, reverse projection, and automatic rewind, though demanded by the advanced cinematographer, do not add to the fundamental subjective enjoyment of the casual motion picture fan, to a degree which justifies their cost, so they are not included.

A projector for the mass market must throw a clear picture on the screen, without ghost or flicker, without noise or clatter; in a word, without subjective distraction. These are essentials, but to insist

that the same standards of these qualities, accepted as proper for theater projection or for commercial or educational work, should apply in the mass-market home would deny home motion pictures to millions.

Six or eight persons at a time constitute an average casual home audience. A picture of the order of 18 in. with a screen distance of about 9 ft is an adequate and convenient arrangement of audience, screen, and projector, in the mass-market livingroom.

A small projection lamp, correctly placed and with the light beam well condensed, gives enjoyable projection under such conditions. To incorporate high-wattage illumination, with the necessary accompaniment of elaborate cooling arrangements and heavier electrical components, capable of auditorium use, into the modest home projector, does not add to the subjective enjoyment of motion pictures in the livingroom sufficiently to justify the extravagant cost. As a matter of fact, such illumination is excessive and unpleasant under most home conditions.

We must now consider a phase of the problem which has a profound bearing on design, but which is very difficult of exact analysis from the standpoint of engineering objectivity. How silent must a silent projector be before it is silent? This requires a careful analysis of each of the various types of operational noise in a projector. Here the engineering staff concerns itself with the matter of a practical balance between elaborateness of design and closeness of tolerance, and the significance of the noise in its subjective effect on the audience. Mechanical noise in a projector is, of course, a question of degree. No projector is completely silent. Wherever it would require elaborate refinement of mechanism to eliminate an operational sound, consideration is first given as to whether that particular sound would detract from the subjective or social enjoyment of the picture performance under home conditions. As long as the noise under examination is of a quality and intensity which appears to be below a distracting level, we feel it is not necessary to increase the precision of the design or decrease allowable tolerances to eliminate it. We endeavor to make moving parts sturdy, not delicate, even though this may mean a sacrifice of some quietness, because we realize that careful maintenance of delicate parts would not be the experience of our mass-produced projector in the user's possession.

Up to this point, the engineering aspects of projector design problems have been quite subjective. They have involved consideration

of the intended use, and the choice of design features which, when combined, serve best the needs which such use require.

That these aspects are not capable of being reduced to formulas and graphs does not bring them outside of the realm of applied engineering To select correctly, and combine properly, the various components of a projector which will serve the mass market to give entertainment adequately and which, at the same time, will approach the ultimate practical level of economy, calls upon two of the most significant attributes of the engineering mind, experience and judgment.

It is not enough, however, to have selected a projector design which is adequately simple. To bring about the low price level necessary to achieve volume, the components must be engineered so as to be capable of manufacture with the least expenditure of labor and machine time. Our engineers have joined together many components into one die casting, intricate, it is true, but so arranged that it is the entire projector except for the moving parts and for the enclosing cover.

This one casting takes the place of 32 separate and various types of individually fabricated parts of a preceding design. It is so conceived that, after reaming a few holes and after painting, it starts down a continuously moving assembly line to have component parts attached to it by successive operators and, at the end of the line, is finally inspected, tested with a film, and then has the enclosing covers affixed and is packed for shipment. This assembly line, consisting of some 30 girls, is designed to handle one projector every 55 sec of the working period. For this to be a successful operation, it is obvious that the assembly must be conducted without hesitation or delay for fitting or selection of parts. This involves a high order of precision engineering thought and accomplishment.

Each individual part naturally must have certain manufacturing tolerances. These tolerances must be so calculated and controlled that they will not stack up to a degree where interference or operational gaps will be interposed.

Long before manufacture of any part was started, the layout on the board was completely analyzed, each part in its relation to every other mating part, and to the assembly as a whole, and tolerances assigned, always with these two ends in view, (*1*) parts must be allowed as generous tolerances as possible, in order to make possible their fabrication by quantity-production methods, and (*2*) the finished projector must satisfy the mass-market requirement of the above-indicated quality of performance.

At certain locations in any projector, components must be held to very close precision. In the intermittent movement, as an example, the cam and the claw have to be made accurately and fitted closely. Our tooling engineers have developed a method of fabricating to very precise dimensions and closely held tolerances on these parts, by successive shaving operations in a punch press, keeping the limits down to a few ten-thousandths. The ingenuity of this method successfully avoids the necessity of finishing these parts on a grinder and yet permitting a random assembly. The resultant economies are importantly reflected in the eventual price.

Certain high-speed gears are accurately generated, low-speed gears are die-cast, and phenolic gears are alternated with metallic gears. The correct choices here make for smoothness and control of noise, without excessive cost.

In short, precision is used where the end justifies the means. Never is precision demanded solely as an abstraction. The tooling engineers, the production engineer, and the chief inspector are constantly at the elbow of the designer to see to it that each part can be tooled adequately, can be fabricated and assembled economically, and can be relied upon for satisfactory use, before any drawing is released.

In assembly, ordinary factory labor is used, not skilled mechanics. This means that jigs and fixtures must be provided to ensure that when the parts are placed in the chassis they are positioned correctly. As an example, the positioning of the shutter and its gear train to the cam, thence to the claw and the sprocket hole in the film, back to the frame of the film in the aperture, all must be exact. An ingenious and rather complicated fixture makes it possible for these components only to go together in such a way that the timing is correct. It is exact to the precise teeth of the intermeshed gears and the claw position and shutter are held to within one degree of arc of rotation.

We hold to accepted standards for flicker of 48 balanced interruptions per second and the cam is designed for a rapid pull-down, using, nevertheless, quite conventional and accepted modes of attack, pull, and release.

While the screen intensity and uniformity are consistent with published standards, here we are constantly studying in our laboratories and sponsoring considerable outside research, as well, to the end that the optical result may become more and more efficient.

Here, as well as in the question of screen definition, the matter of

the subjective impression received by the audience is a controlling factor. For the infrequent critical and more acute user, more elaborate projection lenses are available, and the purchase of such a lens as an accessory can be elected by the occasional individual, without penalizing the majority to whom the difference in performance is not worth the price.

The services of a group of industrial stylists are retained to collaborate with our designers to bring to the finished product an external appearance which will be not only functional, but attractive, and the current result of this joint effort seems to have been a fortunate combination of the practical and the esthetic.

It is seen then, that in the production of mass-market projection equipment, the methods are not haphazard. Engineering talent of a high order, not only mechanical engineering, optical, and electrical engineering, but, so to speak, social or human engineering, is required to bring about the most satisfactory final result in every respect. It is possible for this to be done within the cost limitations of the mass-produced machine where production is scheduled at a rate which can turn out several hundred thousand units each year, introducing a number of neophytes into the hobby, which means universal acceptance of the efforts of scientist and industrialist alike in the exploitation of all levels of equipment, from the beautifully precise and elaborate mechanisms for the professional to the simplified mass models.

From the ranks of the hesitant beginners and the youths of today, learning to enjoy the marvels of home motion pictures with mass-produced equipment, come the experts and intense enthusiasts of tomorrow, graduating into the use of more elaborate products of the professional field.

DISCUSSION

MR. A. SHAPIRO: What is the ratio of pull-down time of the total cycle of your cam?

MR. P. H. CASE: We have two designs currently being developed. One of them, I believe, we are working at 41 deg at the present time. That is the one that will be used in mass production. We have developed a pull-down that is capable of operation without injury to the film at 24 deg.

MR. P. L. KARR: I might add a point to that. In one of the previous designs which was demonstrated here, a very large motor was demonstrated and a pull-down cycle of about 24 deg was indicated. We found that a very light motor of perhaps one fourth to one half of the starting requirements of a universal motor can be used with proper design of the intermittent system so that too much work is not wasted in excessive pressure on the cam during the pull-down cycle.

Mr. R. L. Lewis: It would appear to me from your paper that you are classifying projector designs in five quantities. I want to see if these check: price, lumens, dynamic resolutions, noise, and life of the film.

Mr. Case: That is probably a fair way of stating it, although I classify projection equipment in two major groups, for the mass market and for the professional market. One is where fineness of instrument is the controlling criterion and one where the price is the primary consideration. Both markets exist. Both markets are important. It is by the existence of the first market that the second market is created. People are graduated from the mass market to the professional market.

Mr. Ryan: I am wondering what the area of your stockroom is compared to the area of your manufacture and assembly areas?

Mr. Case: I should say that our stockrooms, raw materials, finished parts, and subassembly occupy a space approximately twice as large as our final assembly space. Of course, that does not take into consideration the fabrication of parts, but assembly is very streamlined. We can produce about 500 projectors on a single table line that is less than half as long as this room.

Dr. E. W. Kellogg: This paper brings to my mind a comment about the Society that has struck me a good many times. Vast ranges of interests and points of view are brought together here in our meetings. There is a decided contrast in the utmost refinement demanded by our Hollywood producers and the low cost, such as this paper brings out, wanted by people who are pursuing a hobby.

I want to make one more comment on a point that Mr. Case made, that a sound projector needs to be more silent than a silent projector.

Mr. Case: That is true. I agree that there is a wide range of interests and activities. I was induced to prepare this paper because of my feeling that the emphasis should be placed in relative proportion on all types of equipment and not exclusively on the more technical aspects. The mass market is a large market and it has to be supplied. It has to be supplied efficiently if the greatest return of the customer's dollar is to be achieved.

PROPOSED STANDARD SPECIFICATIONS FOR FLUTTER OR WOW AS RELATED TO SOUND RECORDS*

REPORT OF THE SMPE COMMITTEE ON SOUND

Distortion caused by speed variation in recording or reproducing has long been a serious source of quality degradation in sound recording. "Flutter" is the term most generally used for this type of distortion by the motion picture industry, while the broadcast recording field knows it as "wow".

Considerable effort has been spent in a quite successful attempt to eliminate, or at least reduce, the causes of this trouble to a reasonable minimum in motion picture equipment, but the resulting effect, which is often quite disturbing when audible, has resisted numerous attempts at definition in relatively simple but adequate terms.

Different methods of measurements have been employed by different groups, resulting in different methods of stating results, which, when quoted without adequate explanation, caused confusion. Some of the earliest methods made use of an oscillographic trace indicating frequency variation. The interpretation of such traces was laborious and required considerable skill. For service work a simpler, portable device was needed in which a direct meter reading of flutter or wow was easily obtained. Such instruments, called flutter bridges, were originally developed by RCA and Western Electric. Other instruments of a similar nature have since been made, but unfortunately, a lack of standardization makes it doubtful that useful comparisons of the readings between instruments can be made at present. It is therefore necessary to set up standard definitions for the terms to be used and for the quantities to be measured.

The Sound Committee undertook to draw up a set of standard specifications for flutter and the first draft was submitted recently to the membership of the Sound Committee and also to representative groups in the broadcast industry for comments. Almost unanimous approval was obtained from the members of the Sound Committee and the original specifications might have been finally incorporated

* Received July 17, 1947.

in this report with only a few minor changes in wording. However, very valuable comments were received from E. W. Kellogg, of the Radio Corporation of America, J. L. Hathaway, of the National Broadcasting Company, and W. H. Offenhauser, Jr., of the Columbia Broadcasting System, and the original specifications have been modified to meet several of their objections and incorporate many of their suggestions. The following revised draft represents a compromise between the original suggestions and the comments received on them and should be acceptable to the overwhelming majority of all concerned with this problem. These comments will be discussed later. The Committee presents the following revised draft as the best compromise it has been able to make and hopes that it will be acceptable to the majority.

PROPOSED STANDARD SPECIFICATIONS FOR FLUTTER OR WOW AS RELATED TO SOUND RECORDS

1.0 Scope and Purpose

This specification defines the terms to be used in describing the flutter or wow found in sound records and sets forth some of the requirements for instrumentation.

2.0 Flutter or Wow

The term "flutter" relates to any deviation of frequency which results, in general, from irregular motion in the recording, duplication, or reproduction of a tone, or from deformation of the record.

Note 1: The term "wow" is colloquial and usually refers to deviation of frequency occurring at a relatively low rate as, for example, a "once-a-revolution" speed variation of phonograph turntables.

3.0 Flutter Rate

Flutter rate is the number of excursions of frequency per second in a tone which has flutter.

Note 1: Each excursion is a complete cycle of deviation, for example, from maximum frequency to minimum frequency and back to maximum frequency at the rate indicated.

Note 2: Flutter is usually periodic with a dominant rate.

Note 3: Two or more flutter rates may be present simultaneously each of which is regarded as a component of the complex variation.

Note 4: Flutter which occurs at random rates close to 0 cps is generally termed drift.

4.0 PER CENT FLUTTER

4.1 Per cent flutter is the ratio of the root-mean-square deviation in frequency of a tone to the average frequency expressed as a percentage.

NOTE 1: Instruments which respond to the average value of frequency deviations or to a function intermediate between average and root-mean-square shall be considered satisfactory for all but the most critical tests, providing the indication is the root-mean-square value for a sinusoidal frequency variation at a single flutter rate.

NOTE 2: Readings of per cent flutter should always be accompanied by a statement as to the band of flutter rates wherein substantially uniform response is obtained.

NOTE 3: Per cent flutter, when measured, should not include the effect of any amplitude variations which may exist simultaneously in the tone.

4.2 "Per cent total flutter" is that value of flutter indicated by an instrument which responds uniformly to all flutter rates up to 200 cps.

NOTE 1: Instruments which respond to all rates up to 120 cps shall be considered adequate for all but the most critical tests.

5.0 FLUTTER TEST FREQUENCY

The standard flutter test frequency for 35-mm film and for disk records shall be 3000 $\pm$ 15 cps.

NOTE 1: This specification is made so that test records may be employed interchangeably on different flutter meters.

NOTE 2: Use of other test frequencies is not precluded providing equivalent flutter readings can be obtained.

6.0 FLUTTER INDEX

Flutter index is a measure of the relative perceptibility of frequency-modulated tones.

NOTE 1: Flutter index I may be expressed as follows:

$$I = \frac{\Delta fx}{r} = \frac{kfx}{100r}.$$

where Δf = r-m-s deviation of frequency from mean in cycles
k = per cent r-m-s flutter
f = frequency of tone
r = flutter rate
x = 1 for rates greater than 5 per second, empirical for lower rates

NOTE 2: For flutter rates 1 to 5 per second the following relations are suggested:

$$x = \frac{r}{5}$$

from which

$$I = \frac{\Delta f}{5} = \frac{kf}{500}.$$

NOTE 3: For flutter rates less than 1 per second the following relations are suggested:

$$x = \frac{r^2}{5}$$

from which

$$I = \frac{\Delta fr}{5} = \frac{kfr}{500}.$$

NOTE 4: The above relations are derived from flutter perceptibility data presented in an article by Albersheim and MacKenzie.[1]

NOTE 5: For the case where $x = 1$, the flutter index, when multiplied by $\sqrt{2}$ is the argument of the Bessel functions of the first kind and the coefficients of the various orders of the Bessel functions have been shown[2] to represent the amplitudes of the corresponding orders of the side frequencies present in a frequency-modulated tone.

NOTE 6: For flutter rates above 5 per second, the ear apparently hears the side frequencies as extraneous effects and therefore will perceive approximately the minimum flutter at the same value of flutter index over a wide range of signal frequencies, percentages of flutter and rates (assuming relatively constant acoustic conditions).

NOTE 7: For flutter rates less than 5 per second, the ear apparently distinguishes the time-frequency variation rather than the discrete side frequencies and so the expression which describes the phenomena becomes more complicated.

NOTE 8: The flutter index of any given device having a constant per cent flutter will vary with the signal frequency, so that the test frequency should always be stated with flutter index in such cases. Unless otherwise stated the flutter index will be assumed to refer to the standard test frequency per Section 5.0.

COMMENTS

The majority of the comments received indicated no objection to the term "flutter", but several felt that the term "wow" should be retained. To quote E. W. Kellogg (RCA), "Rather than put the term 'wow' in parentheses as an accepted alternate to 'flutter' I suggest

that its appropriateness, particularly for low-frequency speed variations, be recognized in distinction to flutter as being more appropriate for rapid fluctuations but both terms are used without such limitations as, for example, 'total flutter (or wow) content.' The use of these words is another example of different practices having originated in different groups of engineers. The term 'wow' may be less dignified than flutter but was coined as an onomatopoeic term."

A few others took a similar view. Another term which has been frequently used was pointed out by C. R. Daily of Paramount, who says: "It is suggested that the word 'drift' be referred to as indicating flutter rates close to 0 cps. The word could then be excluded by a statement that flutter rates close to 0 are equivalent to drift."

The committee feels that a single term should be standard for all types of record frequency deviation regardless of rate. The word "flutter" seems more generally acceptable than "wow" for this term. Should usage retain the word "wow", particularly in phonograph work, this would not detract from the value of the definitions.

The wording of the definition for per cent flutter was suggested by E. W. Kellogg. Further comments by him are as follows: "In the r-m-s system, over-all flutter can theoretically be predicted by taking the square root of the sum of the squares of the r-m-s recorder and reproducer flutters if they are in random relation. There is no corresponding formula for combining measurements made on peak reading or average reading meters. I, therefore, advocate specifications of flutter as an r-m-s value. This will simplify definitions, make for more satisfactory standardization and a more consistent relationship between specified flutter and the resulting quality loss."

The chief disadvantage in specifying per cent flutter as an r-m-s value is that instruments to measure it are more difficult to make than those which respond, say, to an average value. It was felt that the difference between meters responding to an r-m-s and an average function is relatively small, so Note 1 was added to Section 4.1 condoning the use of averaging circuits for all but the most critical measurements. This compares with sound-volume-indicator practice wherein the calibration is for r-m-s values but the rectifying circuits respond more closely to the average value of incoming currents.

Since several flutter rates are generally present, at least in film records, measurements of per cent flutter will usually vary with the bandwidth of the measuring circuits. Therefore, the definition in Section 4.2 of "Per Cent Total Flutter" calls for measurement by an

instrument which responds uniformly to flutter rates from near 0 to 200 cps. Some of the comments received questioned the necessity of setting the upper limit so high. The reason for this is that although the most common disturbance to uniform film motion is at a 96-cps rate, the nature of the effect is such that a strong second harmonic usually accompanies the fundamental (caused by the sudden jerk as the sprocket teeth engage the film). Readings of per cent flutter for the band near 192 cps are frequently as high as 50 per cent of that for the band around 96 cps for film measured on the Western Electric *RA-1015* Flutter-Measuring Set.[3]

However, since some instruments may not be able to pass the wide band mentioned and since, for most applications, this may not be a serious disadvantage, Note 1 was added to Section 4.2 to condone the use of instruments which have uniform response to only 120 cps. It is felt that the response should extend to 120 cycles even for disk-flutter measurement since power-line frequencies may set up motor disturbances or vibrations which produce 120-cycle flutter.

Little objection was expressed to making 3000 cps the standard flutter test frequency, at least for 35-mm film and for disk records. However, J. L. Hathaway (NBC) said: "Our present equipment employs 4000 cps rather than 3000, since 4000 can be more easily referred to WWV's tone in making 'average-speed' measurements. Certain other measuring apparatus uses 1000 cps as standard. I wonder if it is necessary for apparatus to operate on a 3000-cps standard."

It is not the purpose of the standards being set up to preclude the use of any particular test frequency. However, where several test frequencies are employed, difficulty is bound to ensue in correlating the readings of different instruments and also in supplying "standard" test records. A 3000-cycle tone was selected because, in general, it is simpler to make a sensitive instrument at a relatively high frequency than at a low one and also because a considerable number of instruments in use now employ that frequency. For measurements with 16-mm film, 8-mm film, and possibly some wire recording systems, lower test frequencies may be required.

Comment on Section 6.0 Flutter Index was the most varied of all. This is a new term which few have used and there was, naturally, considerable question as to its meaning and value.

As anyone who has worked with the flutter problem knows, the per cent flutter present in a record is of little significance unless the rate and signal frequency of the variation are taken into consideration.

Thus, with a given signal frequency, roughly ten times the percentage of flutter is required at a rate of 100 per second to be just noticeable as is required at 10 per second. A term indicative of flutter perceptibility without qualification as to rate would be quite valuable.

Fortunately there appears to be a fundamental relationship between flutter perceptibility, rate, and signal frequency, at least for a considerable range of values. Although this relationship has not been

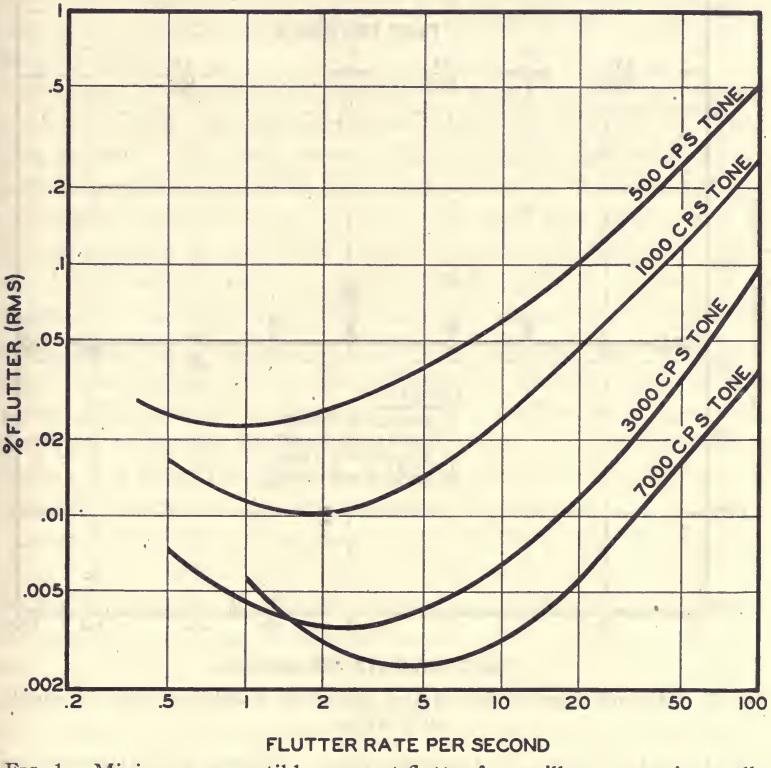

FIG. 1. Minimum perceptible per cent flutter for oscillator tones in small auditorium.

specifically pointed out in the literature, it is readily derived from published reports.[1] Curves summarizing the per cent flutter, at threshold for various rates and signal frequencies, which are the result of extensive tests at Bell Telephone Laboratories, are shown in Fig. 1 (taken from reference 1). The per cent flutter values shown are 0.707 times those of the original report in order to correlate with the

r-m-s definition of per cent flutter given herein. The original data defined per cent flutter in terms of the peak deviation rather than the r-m-s values. An additional curve for 7000 cycles has been added from data obtained from the original tests. In Fig. 2 is plotted the relation of flutter index *versus* rate for several signal frequencies

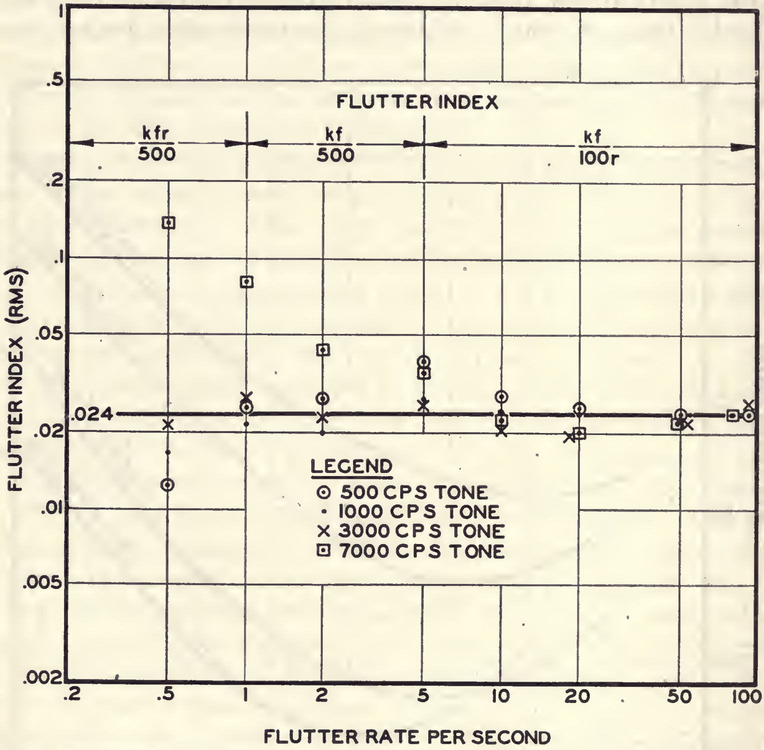

FIG. 2. Minimum perceptible flutter index for oscillator tones in small auditorium.

using the data of Fig. 1. Here the value of threshold flutter index is almost constant at about 0.024 between rates of 5 and 100 cps at a signal frequency of 1000 (where X is unity). Frequencies of 3000 and 7000 cycles show a somewhat less constant index but do not depart greatly. At 500 cycles the greatest departure from the constant flutter-index relation is obtained but this is of lesser importance since, with a given percentage of flutter, the condition will be most perceptible in higher frequencies.

It is interesting to note that the flutter index is equal to the per cent

flutter when the signal frequency is 100 times the rate frequency. Thus the two are equal for the 3000-cycle signal at a rate of 30 per second. This constitutes a fortunate relationship since flutter-index values can be considered as simply weighted per cent flutter values where so desired in instrumentation.

From the data given in Figs. 1 and 2, one can say that, at least for the live auditorium wherein the tests were conducted, flutter became perceptible when the flutter index was approximately 0.024 for all rates between about 5 and 100 per second and for all signal frequencies shown thereon.

A reason for the above relationship is readily found by a consideration of the mathematical analysis of frequency modulation. As has been shown[2, 4, 5, 6] a frequency-modulated signal consists of a carrier and one or more pairs of side frequencies separated from the carrier by an amount equal to $\pm$r, $\pm$2r, $\pm$3r, $\pm$4r, *etc.* The number and relative amplitudes of these side frequencies are determined by the so-called modulation index α, which is defined in the literature as Kf/fm where K is the fractional peak change of carrier frequency and fm is the rate. This is similar to the flutter index per Section 6.0 of the specification when $X = 1$, except that the former refers to peak-frequency changes whereas the latter relates to root-mean-square changes which are more suitable for instrumentation. The flutter index per Section 6.0 must therefore be multiplied by $\sqrt{2}$ to equal the peak modulation index α, used in mathematical analysis.

As stated in Note 5 of Section 6.0, the flutter index when multiplied by $\sqrt{2}$ is the argument of the Bessel functions of the first kind, and the coefficients of the various orders have been shown to represent the amplitudes of the corresponding orders of side frequencies present. Reference to a table of Bessel functions will show that when the argument (flutter index multiplied by $\sqrt{2}$) has a value of 0.03, only the carrier and the adjacent pair of side frequencies are significant. For this case, the amplitude of each side frequency is approximately 1.5 per cent of the carrier amplitude. Since this relation holds for any combination of signal frequency, rate, and percentage of flutter in which the peak modulation index is 0.03 (r-m-s flutter index $\pm$0.021) it is not surprising that the ear hears roughly the same degree of flutter in all cases (with the exceptions pointed out in Notes 2 and 3 of Section 6.0). In this connection, a similarity is noted to harmonic distortion wherein harmonic components having an amplitude between 1 and 2 per cent of the fundamental become noticeable.

Thus there seems to be a fundamental basis for the term "Flutter Index", both in theory and by observation. Further investigations may show shortcomings and exceptions to the relationship, but the Committee feels that the term as defined should nevertheless prove a useful one and any future modifications of it may be taken care of by the value assigned to the term X given in the expression of Section 6.0.

Values for flutter index at rates below 5 cps were computed using the suggested values for X given in Notes 2 and 3, of Section 6.0. These show little change, in general, as rate and signal-frequency change, indicating a good approximation is obtained by the expressions for X, at least for the particular listening tests concerned.

The qualifications given for the index for rates below 5 per second and referred to in Notes 2, 3, 6, and 7, of Section 6.0 are, of course, purely empirical and subject to future evaluation. The value suggested for X for rates of 1 to 5 cycles makes the index independent of rate between 1 and 5 cycles, and directly proportional to per cent flutter. This is in agreement with general experience which shows that flutter perceptibility does not change greatly between about 1 and 5 cycles (see Fig. 1). The value suggested for X for rates below 1 per second causes the index to drop proportionally with rate below 1 per second. This relation was proposed by J. L. Hathaway (NBC) who states, "We can find no evidence that the perceptibility of wow changes greatly between the rates of about 1 and 8 per second, and therefore believe that within this range the index should be a function of percentage of wow only. Going below 1 per second, it is apparent that perceptibility falls off, reaching zero for extremely slow variations. Thus up to 1 per second the index should be a direct function of rate and percentage wow. Above about 8 per second it appears that perceptibility of wow dimimishes.

"We propose that the wow index be defined as the perceptibility of wow and that, based upon present data, this should be directly proportional to the wow percentage and also a function of wow rate. The index may be expressed by

$$I = Wx$$

where I = wow index
W = percentage wow
x = $100\ R$ when $R < 1$
= 100 when $1 < R < 8$
= $800/R$ when $R > 8$
R = wow rate"

It will be noted that the above expression takes no account of the signal frequency, whereas the value defined in Section 6.0 does. If measurements are always made at the same frequency and perceptibility is in terms of that frequency, it might be satisfactory to ignore the signal frequency. However, the committee feels that since the signal frequency is an essential factor in the perceptibility of flutter tones it should be included in the expression for flutter index. Obviously, if the flutter index for any particular record is stated, that value can be true of only one signal frequency, and it would seem reasonable to express it for frequency of measurement, namely, the standard 3000 cycles. For lower frequencies the index would fall off and for higher frequencies it would be proportionally higher. For this reason a measured value of flutter index must be stated with the corresponding signal frequency as, for example, "3000-cycle flutter index".

The fact that flutter index varies with frequency for a given record or machine is reasonable since with a given per cent flutter and rate the higher frequencies will appear to have the most flutter and at the lower frequencies the flutter may seem to disappear completely.

Hathaway's recommendation would place the transition point where X ceases to be unity at 8 cycles instead of 5 as outlined in 6.0. This, however, is a rather small difference. The committee feels that the data analyzed[1] to obtain the figure used herein is probably somewhat more extensive than that used by Hathaway in arriving at his conclusion. The exact point of transition is not thought to be vital in any event and the figures presented by Hathaway should be considered reasonably close to those presented herein.

The question has been raised as to what use there is for the term "Flutter Index". The most important one is that it provides the user with a scale with which to judge the relative perceptibility of a given flutter condition. The per cent flutter reading does not give him such a measure unless weighed against rate. A second reason is that instruments will probably be made eventually to measure flutter index instead of per cent flutter.

Kellogg has proposed a somewhat different concept for a flutter index as follows:

"I think it cannot be very far from the truth to assume that the magnitude of the damage to quality is proportional to the square of the speed fluctuation. The fact that there is a threshold of objectionable wow which varies from one person to another and varies with

the type of reproduced sound, and that above the threshold the impairment seems to increase rapidly, indicates that the square law is probably not a bad approximation."

The flutter index as defined does not appear to convey such a relation, although it does not contradict it. Actually, the flutter index is an expression for relative perceptibility at the threshold point. Interest is generally centered in whether a given amount of flutter is noticeable rather than in just how bad it is, beyond the point of perceptibility.

Adoption of the recommendations in this specification will, it is believed, serve to co-ordinate measurements and standardize instruments in a field of increasing importance.

The chairman of your Committee wishes to express his appreciation to the members for their invaluable assistance and particularly to R. R. Scoville without whose help and guidance this report would not have been possible.

JOHN G. FRAYNE, *Chairman*

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R. J. ENGLER	W. A. MUELLER	E. I. SPONABLE
R. T. VAN NIMAN	J. E. VOLKMANN	

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PROPOSED STANDARD FOR 35-MM FLUTTER TEST FILMS*

REPORT OF THE SMPE COMMITTEE ON SOUND

Industry-wide agreement on a standard method of measuring flutter in 35-mm motion picture sound film reproducers is now being sought by the motion picture industry through the Society of Motion Picture Engineers and the Research Council of the Academy of Motion Picture Arts and Sciences. The ultimate success of the project depends primarily upon industry acceptance of the basic standards.

A parallel report of the Sound Committee, entitled "Proposed Standard Specifications for Flutter or Wow in Sound Records", attempts to set up standard definitions for the terms used in flutter analysis, and to standardize certain characteristics of instruments required to measure flutter. This should place sufficient requirements on instruments to ensure that measurements made by different persons on different apparatus will give the same results.

This report describes the characteristics of a substantially flutter-free test film, of known and controlled characteristics, that can be produced practically and that will be available to serve as a reliable and uniform source of test signals. The proposal is presented as a form of specification stipulating the essential characteristics of the finished film, but not restricting the type of sound track, the recording equipment, or the type of film used.

Pertinent references to previously published material on the flutter question were included in the report mentioned above and for that reason are not repeated here.

PROPOSED STANDARD FOR 35-MM FLUTTER TEST FILMS

1.0 Scope and Purpose

1.1 This specification defines the general characteristics of test films suitable for flutter measurements upon 35-mm motion picture film reproducers.

2.0 Type of Film Record

2.1 The test film shall carry a sound track meeting standard release specifications with either variable-density or variable-area modulation.

* Received July 17, 1947.

2.2 The test film shall be an original record processed as outlined in Section 4.0.

3.0 SIGNAL FREQUENCY

3.1 The signal frequency shall be 3000 ± 15 cps, sinusoidal, when run at a standard speed of 90 feet per minute.

3.2 The signal frequency shall be recorded at an amplitude level of approximately 80 per cent of the overload value of the modulator or medium.

4.0 FILM PROCESSING

4.1 Variable-area records shall be processed in a manner which produces minimum cross modulation according to the standard test[1] for this type of record when reproduced as a negative.

4.2 Variable-density records shall be processed as high-contrast toe negatives in a manner which produces minimum intermodulation according to the standard test for this type of record.[2]

NOTE 1: Variable-density films should be processed in such a manner that sprocket-hole modulation, due to uneven development, will be at least 30 decibels below full modulation.

NOTE 2: The signal-to-noise ratio of the test film shall be at least 30 decibels when reproduced in the normal manner.

5.0 FLUTTER CONTENT

5.1 The flutter content of the test film shall be specified by the supplier. The figure or figures furnished shall be as obtained when the film is reproduced on a device which is relatively free of flutter and measured on a flutter-measuring instrument which conforms to the specifications given in "Proposed Standard Specifications for Flutter or Wow as Related to Sound Records".

5.2 The "Per Cent Total Flutter" shall be a minimum and shall not exceed 0.06 per cent.

5.3 The "Per Cent Flutter" at any rate within an octave band shall not exceed 0.035 per cent.

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Catalog of TEST FILMS

available

from

Motion Picture Research Council, Inc.

1421 North Western Avenue
Hollywood 27, California

and

Society of Motion Picture Engineers

Hotel Pennsylvania
New York 1, New York

TEST FILMS

The 35-mm and 16-mm test films listed in this catalog are made available by the Motion Picture Research Council and the Society of Motion Picture Engineers to be of more service to the motion picture industry in general and to the exhibitor in particular.

Prices include shipping charges to all points within the United States.

PLEASE ORDER BY NAME, CODE NUMBER, AND TYPE.

All test film is sold on a cost basis. Therefore, no cash discounts are given and facilities for extending credit are not available.

INDEX OF TEST FILMS

Test Film	Code No.	Length (in Feet)	Price
35-Mm Visual Test Film	*VTF-1*	450	$ 17.50
Focus-and-Alignment Section	*VTF-FAS*	100	5.00
Travel-Ghost Target Section	*VTF-TGS*	100	5.00
Jump-and-Weave Target Section	*VTF-JWS*	100	5.00
35-Mm Theater Sound Test Film	*ASTR-3*	500	17.50
35-Mm Multifrequency Test Film			
Type A—Laboratory Type	*APFA-1*	450	25.00
Type B—Service Type	*ASFA-1*	300	17.50
35-Mm Transmission Test Film	*TA-1*	250	17.50
35-Mm Buzz-Track Test Film	*ABZT-1*	50 min*	0.04/ft
35-Mm Scanning-Beam Illumination Test Film			
Type A—17 Position Track	*A17P-1*	230	12.50
Type B—Snake Track	*AST8-1*	8	0.50
35-Mm Sound-Focusing Test Film			
Type A—9000-Cycle Track	*A9KC-1*	50 min	0.035/ft
Type B—7000-Cycle Track (Area)	*A7KC-1*	50 min	0.035/ft
Type C—7000-Cycle Track (Density)	*D7KC-1*	50 min	0.035/ft
Type C—Acetate Base	*D7KCS-1*	50 min	0.04/ft
35-Mm 3000-Cycle Flutter Test Film	*A3KC-1*	50 min	0.05/ft
35-Mm 1000-Cycle Balancing Test Film			
For Two Machines	*ABL2-1*	14	0.50
For Three Machines	*ABL3-1*	21	0.75
1000-Cycle Test Film	*ABLN-1*	50 min	0.035/ft
35-Mm Multifrequency Warble Test Film	*APWA-1*	450	25.00
16-Mm Sound-Projector Test Film	*Z52.2*	200	12.50
16-Mm Multifrequency Test Film	*Z22.44*	150	41.25
16-Mm Buzz-Track Test Film	*Z52.10*	100	27.50
16-Mm Scanning-Beam Illumination Test Film			
Laboratory Type	*Z52.7-L*	100	27.50
Service Type	*Z52.7-S*	100	27.50
16-Mm Sound-Focusing Test Film			
Laboratory Type	*Z22.42-7000*	100	27.50
Service Type	*Z22.42-5000*	100	27.50
16-Mm 3000-Cycle Flutter Test Film	*Z22.43*	380	104.50
16-Mm 400-Cycle Signal-Level Test Film	*Z22.45*	100	27.50

* Minimum.

CATALOG OF TEST FILMS

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE
35-Mm Visual Test Film	*VTF-1*	450	$17.50

The Visual Test Film is a print on safety stock, picture only containing four targets to check focus and alignment, travel ghost, jump and weave, and lens aberration. This test film is used when installing new projectors and screens or performing maintenance operation on existing equipment.

The Focus-and-Alignment target shows whether or not picture size and screen masking are correct, and whether the projected picture is centered properly on the screen.

The Travel-Ghost target shows improper timing of the shutter quite readily and gives a clear indication of the correct adjustment as the timing is being corrected.

The Jump-and-Weave target gives an accurate indication of the unsteadiness of the projected picture. Picture jump is measured in per cent of picture height, and picture weave is measured in per cent of picture width.

The Lens-Aberration target shows picture distortion and gives an indication of the lack of sharpness that will be present in pictures shown on any particular projector.

Explanatory titles precede each section and an instruction booklet is furnished giving complete details on its proper use.

Because some users prefer loops or continuous lengths of the separate target sections for adjusting machines, one at a time or in pairs, separate sections of the first three targets have been made available. They may be purchased separately in 100- to 900-ft lengths in multiples of 100 ft.

Focus-and-Alignment Section	*VTF-FAS*	100	$5.00
Travel-Ghost Target Section	*VTF-TGS*	100	5.00
Jump-and-Weave Target Section	*VTF-JWS*	100	5.00
35-Mm Theater Sound Test Film	*ASTR-3*	500	$17.50

The Theater Sound Test Film is a print on nitrate base containing picture and sound and is used to check the over-all sound quality in the theater. Included are main title music to check the frequency range and the high- and low-frequency balance, specially selected samples of current dialog recording to check the frequency response, and a piano recording to check flutter.

Standard electrical characteristics for the commonly used types of two-way theater reproducing equipment were specified by the Research Council early in 1937 in order that studios might re-record for the best possible reproduction on a theater sound system set to a standard electrical characteristic applicable to that

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE

system. The standard electrical characteristics were arrived at after listening tests were conducted in various representative theaters. During these tests the equipment in each theater was adjusted to various settings of the electrical characteristic. That setting which gave the optimum reproduction was established as the standard for that particular loudspeaker system. For the listening tests necessary in arriving at the standard electrical characteristics, the Committee devised a test film containing sample recordings of music and dialog from all the studios. The use of this film was so successful that prints subsequently were made available for the use of theater service engineers.

This test film has been revised from time to time, in order to increase its value for theater service engineering use.

The current version, designated Theater Sound Test Film *ASTR-3*, contains three dialog samples, a choral-music sample, a vocal (single-voice) music sample, and a sound-effect sample, totaling approximately 500 ft in length. A title is superimposed over the picture indicating the particular sound difficulty which that sample demonstrates. The material contained in the film is not necessarily the best recording available, but each sample has been selected to demonstrate a particular point of difficulty in the adjustment of theater sound systems.

35-Mm Multifrequency Test Film

Type A—Laboratory Type	*APFA-1*	450	$25.00
Type B—Service Type	*ASFA-1*	300	17.50

The Multifrequency Test Film is a variable-area print on nitrate base and is used to obtain the electrical frequency response at the output of the power amplifier. Each print is individually calibrated, and correction factors, accurate to within $\pm$ 0.25 db, are provided with each film. The response within any one frequency will vary less than $\pm$ 0.25 db.

Type A (Laboratory Type), normally used by manufacturers and in the installation of equipment contains the following frequencies each, preceded by a spoken announcement:

cps	cps	cps	cps
1000	200	1500	6000
40	300	2000	7000
55	400	2500	8000
70	500	3000	9000
100	700	4000	10000
150	1000	5000	1000

Type B (Service Type), normally used in routine theater servicing, includes the following frequencies, each preceded by a spoken announcement:

cps	cps	cps	cps
1000	300	2500	5000
40	500	3000	6000
70	1000	3500	7000
100	2000	4000	8000

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE
35-Mm Transmission Test Film	*TA-1*	250	$17.50

The Transmission Test Film is a print on safety stock and is used to check the position of the scanning beam, the electrical frequency response of the system, and flutter.

The film contains two sound tracks, one on each side of the film, which are printed head to tail thereby making rewinding unnecessary when playing both tracks.

The first track, entitled multifrequency test, starts with a short section of buzz track to check the guide-roller adjustment. Next is a series of the following constant frequencies: 1000, 40, 70, 130, 300, 500, 2000, 3000, 7000, and 8000 cps. The low frequencies are recorded at a reduced level and announcements precede all sections up to and including the 3000-cycle section. An unmodulated track of average density is included between the 7000- and 8000-cycle tones to evaluate the effect of film noise on the readings.

The second track, on the opposite side of the film, entitled flutter test, contains 60 ft of sustained piano chords followed by a 3000-cycle tone. While the flutter in this print is low, it is intended only as an aural check. For the bridge-type of flutter measurement, the toe-recorded variable-density negative (*A3KC-1*) should be used.

35-Mm Buzz-Track Test Film	*ABZT-1*	50 min	$0.04/ft

The Buzz-Track Test Film is a print on nitrate base and is used for checking scanning-beam placement. The track consists of an 0.087-in. opaque center with a frequency of 300 cycles on the picture side and a frequency of 1000 cycles on the sprocket side. These tracks are accurately located on the film so that when the film is run on a projector in correct adjustment and free from weave, no sound is heard. If the scanning-light beam is out of adjustment laterally, either the 300- or the 1000-cycle tone will be heard.

This film is available in 50- to 500-ft lengths in multiples of 50 ft.

35-Mm Scanning-Beam Illumination Test Film			
Type A—17-Position Track	*A17P-1*	230	$12.50
Type B—Snake Track	*AST8-1*	8	0.50

The Scanning-Beam Illumination Test Film is a print on nitrate base and is used to check the uniformity of illumination across the scanning slit.

Type A (17-Position Track) is used by manufacturers or on new installations. The film contains 17 incremental 1000-cycle tracks, all with the same amplitude of approximately 0.007 in. The tracks appear on the film in succession, each preceded by an announcement identifying the track number. The 17 tracks cover a width greater than the standard scanning beam. By running this test film and observing the indications of the output meter it is possible to correct unevenness of illumination and bring the variation of output within a limit of $\pm$ 1.5 db, which is the recommended maximum variation. This is accomplished by adjusting or replacing the exciter lamp.

A calibration sheet giving the exact position of each track from the guided edge is provided with each film.

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE

Type B (Snake Track) is used as an 8-ft loop for quick service adjustment of the scanning-beam illumination. It contains a 1000-cycle track with a 0.007-in. amplitude placed on the film in such a way that the track moves across the scanning slit from one edge to the other at a uniform rate.

In order to maintain a constant length of track, and thus hold the scanned area constant, the usual type of film splice should not be used in making up this loop. Instead, a butt-end splice should be employed, obtained by placing the ends of the print securely against one another without any overlap and joining the two ends with transparent tape, such as Scotch cellophane tape. Experience has shown this splice to be very practicable as it may be remade without any loss of film. In addition, this type of splice disturbs the reading of the volume indicator less than the conventional overlap splice. This film has been prepared for testing the uniformity of the illumination across the scanning slit and is not intended for use to determine slit placement adjustment, for which the Buzz Track should be used.

35-Mm Sound-Focusing Test Film

Type A—9000-Cycle Track	*A9KC-1*	50 min	$0.035/ft
Type B—7000-Cycle Track (Area)	*A7KC-1*	50 min	0.035/ft
Type C—7000-Cycle Track (Density)	*D7KC-1*	50 min	0.035/ft
Type C—Acetate Base	*D7KCS-1*	50 min	0.004/ft

The Sound-Focusing Test Films are prints on nitrate base (except *D7KCS-1* on acetate base) and are used to adjust the focus and azimuth of soundhead optical systems.

Type A—9000-Cycle Track (*A9KC-1*) contains a 9000-cycle variable-area tone recorded at 1 db below 100 per cent modulation with a power output variation of less than $\pm$0.25 db. This film is normally used by manufacturers and laboratories. It is not recommended for theater use.

Type B—7000-Cycle Track (*A7KC-1*) contains a 7000-cycle variable-area tone recorded at 2 db below 100 per cent modulation with a power output variation of less than $\pm$0.25 db. This film is used for servicing theater equipment.

Type C—7000-Cycle Track (*D7KC-1*) contains a 7000-cycle variable-density tone recorded at 2 db below 100 per cent modulation with a power output variation of less than $\pm$0.25 db. This film is used for servicing theater equipment. *Type C* is also available on acetate base (*D7KCS-1*).

These films are available in 50- to 200-ft lengths in multiples of 50 ft.

35-Mm 3000-Cycle Flutter Test Film	*A3KC-1*	50 min	$0.05/ft

The 3000-Cycle Flutter Test Film is a toe-recorded variable-density negative on nitrate base and is used in measuring flutter. A flutter bridge is required to make this measurement. The total flutter of this film is not more than 0.06 per cent. A complete analysis of the flutter content is furnished with each purchase of film.

This film is available in 50- to 1000-ft lengths in multiples of 50 ft.

35-Mm 1000-Cycle Balancing Test Film

For Two Machines	*ABL2-1*	14	$0.50
For Three Machines	*ABL3-1*	21	0.75
1000-Cycle Test Film	*ABLN-1*	50 min	0.035/ft

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE

The 1000-Cycle Balancing Film is a print on nitrate base and is used as a loop to measure and adjust the power-level output of two or more projection machines. It contains a 1000-cycle variable-area tone with a power-level output variation of less than 0.25 db.

The *ABL2-1* contains sufficient film for making loops for two machines and the *ABL3-1* contains sufficient film to make loops for three machines. An instruction booklet is furnished with these balancing loops.

This film is also available in single lengths of 50 to 200 ft in multiples of 50 ft.

35-Mm Multifrequency Warble Test Film	*APWA-1*	450	$25.00

The Multifrequency Warble Test Film is a variable-area print on nitrate base and is used to make acoustical-response measurements. This measurement requires the use of a sound-level meter. Each print is individually calibrated and correction factors are provided with each film. This film contains the following frequencies with the indicated amount and rate of warble for each frequency:

Frequency	Amount of Warble	Rate of Warble	Frequency	Amount of Warble	Rate of Warble
750	±250cps	5 cps	900	±12$^1/_2$%	5cps
40	±12$^1/_2$%	2$^1/_2$cps	1000*	±12$^1/_2$%	5cps
50	±12$^1/_2$%	2$^1/_2$cps	1250	±125cps	5cps
55	±12$^1/_2$%	2$^1/_2$cps	1500	±125cps	5cps
65	±12$^1/_2$%	2$^1/_2$cps	1750	±125cps	5cps
70	±12$^1/_2$%	2$^1/_2$cps	2000	±125cps	5cps
85	±12$^1/_2$%	2$^1/_2$cps	2250	±125cps	5cps
100*	±12$^1/_2$%	3 cps	2500*	±125cps	5cps
130	±12$^1/_2$%	3 cps	2750	±125cps	5cps
150	±12$^1/_2$%	3 cps	3000	±125cps	5cps
175	±12$^1/_2$%	3 cps	3500	±125cps	5cps
200	±12$^1/_2$%	4 cps	4000	±125cps	5cps
250*	±12$^1/_2$%	4 cps	4500	±125cps	5cps
300	±12$^1/_2$%	4 cps	5000*	±125cps	5cps
350	±12$^1/_2$%	4 cps	5500	±125cps	5cps
400	±12$^1/_2$%	4 cps	6000	±125cps	5cps
450	±12$^1/_2$%	4 cps	6500	±125cps	5cps
500*	±12$^1/_2$%	5 cps	7000	±125cps	5cps
600	±12$^1/_2$%	5 cps	7500	±125cps	5cps
700	±12$^1/_2$%	5 cps	8000	±125cps	5cps
800	±12$^1/_2$%	5 cps			

* An identifying beat tone precedes these frequencies.

16-Mm Sound-Projector Test Film	*Z52.2*	200	$12.50

The 16-Mm Sound-Projector Test Film is a print on safety base, containing picture and sound, and is used to check the adjustment of 16-mm sound motion picture projection equipment and to judge the acoustics of the room in which

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE

the equipment is operated. This film is the 16-mm version of the 35-mm Theater Sound Test Film (*ASTR-3*) and contains the same main title and choral music, dialog samples, and piano recording. The picture has been optically reduced from 35 to 16 mm and the sound re-recorded from 35 to 16 mm.

16-Mm Multifrequency Test Film	*Z22.44*	150	$41.25

The Multifrequency Test Film is a direct-positive original recording on safety base and is used to obtain the electrical-frequency response at the output of the power amplifier. Each film is individually calibrated on equipment correct within ± 0.25 db up through 3000 cycles and within ± 0.5 db above 3000 and through 7000 cycles. The deviation from the intended flat-response characteristic (assuming negligible reproducing light-beam width) is stated as a correction for each frequency which will give the true level when it is added algebraically to the output-level measurement obtained when using the film.

This test film contains the following series of frequencies, each preceded by a spoken announcement:

cps	cps	cps	cps
400	300	2000	5000
50	500	3000	6000
100	1000	4000	7000
200			400

16-Mm Buzz-Track Test Film	*Z52.10*	100	$27.50

The Buzz-Track Test Film is an original negative on safety base and is used for checking scanning-beam placement. The track consists of an 0.076-in. opaque center with a frequency of 300 cycles on the picture side and a frequency of 1000 cycles on the sprocket side. These tracks are accurately located on the film so that when the film is run on a projector in correct adjustment and free from weave, no sound is heard. Either or both the 1000- and 300-cycle tones will be heard. however, if the scanning-light beam is out of position.

16-Mm Scanning-Beam Illumination Test Film			
Laboratory Type	*Z52.7-L*	100	$27.50
Service Type	*Z52.7-S*	100	27.50

The Scanning-Beam Illumination Test Film is a print on safety base and carries a narrow sound track (0.005 in. wide) modulated at constant level by a 1000-cycle tone. The location of this sound track changes at a uniform rate along the length of the film from a position just inside one edge of the scanned area to a position just inside the opposite edge of the scanned area. The narrow 1000-cycle sound track sweeps across the scanning-light beam from one end to the other at a uniform rate, the position of the sound track relative to the ends of the light beam at any instant being shown by an animated diagram appearing in the picture area.

If the scanning-beam illumination were absolutely uniform across the width of the scanned area, the output level of the 1000-cycle tone would be constant. In practice, however, some variation of an output-meter reading will always be

TEST FILM	CODE NO.	LENGTH (in Feet)	PRICE

observed. By running a loop of the film continuously and observing the indications of the output meter while adjustments are made, it is usually possible to correct unevenness of illumination and bring the variation of output within a limit of $\pm$ 1.5 db.

The *Laboratory Type* may be spliced into 34-ft loops and the *Service Type* may be spliced into $3^1/_2$-ft loops. Each type is available in 100-ft lengths.

16-Mm Sound-Focusing Test Film			
Laboratory Type	*Z22.42-7000*	100	$27.50
Service Type	*Z22.42-5000*	100	27.50

The Sound-Focusing Test Film is an original negative on safety base and carries a special "square-wave" track, chosen because its output changes more rapidly with changes in the focus of the sound optical system of the projector than the output from the usual "sine-wave" high-frequency track. The "square-wave" track also gives a more sensitive indication of the errors of the "azimuth" adjustment of the sound-reproducing light beam.

The Sound-Focusing Test Film is made in two types: *Laboratory Type*, a 7000-cycle record for manufacturing and precision adjustment of the focus and azimuth of the sound optical system, and *Service Type*, a 5000-cycle record for quick service adjustment.

16-Mm 3000-Cycle Flutter Test Film	*Z22.43*	380	$104.50

The 3000-Cycle Flutter Test Film is a direct-positive original recording on safety base and carries a 3000-cycle tone having extremely low flutter content for use in measuring the flutter introduced by 16-mm sound reproducers. The recorded frequency is within 25 cycles of the 3000-cycle frequency, the output level is constant within 0.25 db, and the total flutter content of the film at the time of shipment is less than 0.1 per cent.

16-Mm 400-Cycle Signal-Level Test Film	*Z22.45*	100	$27.50

The 400-Cycle Signal-Level Test Film is a direct-positive original recording designed to furnish as nearly as is practicable an absolute standard of recorded signal level for use in measuring the effective amplification and sound output of 16-mm sound motion picture projectors, taking into account the sound optical system and phototube, as well as the amplifier and loudspeaker.

A definite output level is determined by specifying the amplitude of the recorded signal, the density of the image, and the combined base and fog density of the clear part of the sound track within narrow limits. The specified level is approximately 2 db below the maximum level possible and is about equal to the highest level that is to be expected in most recording, since in commercial practice the image density is usually not so great and the fog density not so low as the values specified for this film.

The actual measured values of signal amplitude, image density, and fog density are given with each film, together with the corresponding calculated value of overall deviation from the intended standard signal level.

RECENT AMERICAN STANDARDS ON MOTION PICTURES

FOREWORD

The following six American Standards on Motion Pictures have been approved recently by the American Standards Association.

The Standard, "Dimensions for 16-Tooth 35-Mm Motion Picture Projector Sprockets", *Z22.35-1947*, is a revision of *Z22.35-1930*. It will be noticed that the revised Standard includes a change in the *B* dimension from 0.945 in. to 0.943 $\pm$ 0.001 in. This change was recommended by the Standards Subcommittee on 35-Mm Sprockets after tests of film and sprocket life were conducted, using sprockets with three different *B* dimensions, in several theaters.

The four standards on cutting and perforating, *Z22.5-1947*, *Z22.12-1947*, *Z22.17-1947*, and *Z22.36-1947* are also revisions of older standards. The dimensioning technique has been changed to conform with actual methods of measurement, that is, from edge to edge of the hole rather than from center to center. In addition, the tolerances and form have been brought up to date.

The Standard on "Nomenclature for Motion Picture Film Used in Studios and Processing Laboratories", *Z22.56-1947* was formerly approved as American War Standard *Z52.14-1944*. This Standard was printed in the April, 1945, JOURNAL and since the only change involved is that of the foreword, it is not being reprinted here.

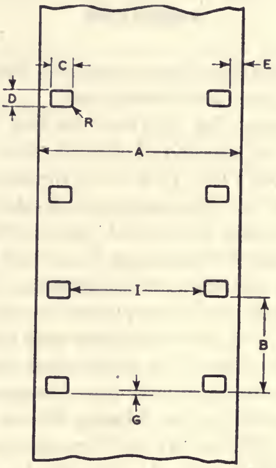
Copies of these six standards and several more, which will be published in the JOURNAL shortly, will be available from the General Office of the Society in the very near future. It is planned to distribute these standards on $8^1/_2$- $\times$ 11-in. sheets, punched to fit the SMPE Standards binder.

AMERICAN STANDARDS

Z22.5 -1947	Cutting and Perforating Dimensions for 16-Mm Silent Motion Picture Negative and Positive Raw Stock
Z22.12-1947	Cutting and Perforating Dimensions for 16-Mm Sound Motion Picture Negative and Positive Raw Stock
Z22.17-1947	Cutting and Perforating Dimensions for 8-Mm Motion Picture Negative and Positive Raw Stock
Z22.35-1947	Dimensions for 16-Tooth 35-Mm Motion Picture Projector Sprockets
Z22.36-1947	Cutting and Perforating Dimensions for 35-Mm Motion Picture Positive Raw Stock
Z22.56-1947	Nomenclature for Motion Picture Film Used in Studios and Processing Laboratories

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Silent Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.5-1947
Revision of
Z22.5-1941



Dimensions	Inches	Millimeters
A	0.629 ± 0.001	15.98 ± 0.03
†B*	0.3000 ± 0.0005	7.620 ± 0.013
C	0.0720 ± 0.0004	1.83 ± 0.01
D	0.0500 ± 0.0004	1.27 ± 0.01
†E	0.036 ± 0.002	0.91 ± 0.05
†G	Not > 0.001	Not > 0.025
†I	0.413 ± 0.001	10.490 ± 0.025
L‡	30.00 ± 0.03	762.00 ± 0.76
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.5-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.5-1941.

‡This dimension represents the length of any 100 consecutive perforation intervals.

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Silent Motion Picture Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.5-1947
Revision of Z22.5-1941

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the film, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness of projection.

Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important. This is one of the reasons for the method of specifying uniformity in dimension B.

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Sound Motion Picture Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.12-1947
Revision of Z22.12-1941

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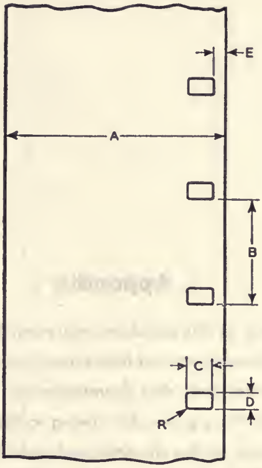

Dimensions	Inches	Millimeters
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†B*	0.3000 ± 0.0005	7.620 ± 0.013
C	0.0720 ± 0.0004	1.83 ± 0.01
D	0.0500 ± 0.0004	1.27 ± 0.01
†E	0.036 ± 0.002	0.91 ± 0.05
L‡	30.00 ± 0.03	762.00 ± 0.76
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.12-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.12-1941.

‡This dimension represents the length of any 100 consecutive perforation intervals.

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Sound Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.12-1947
Revision of
Z22.12-1941

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the film, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

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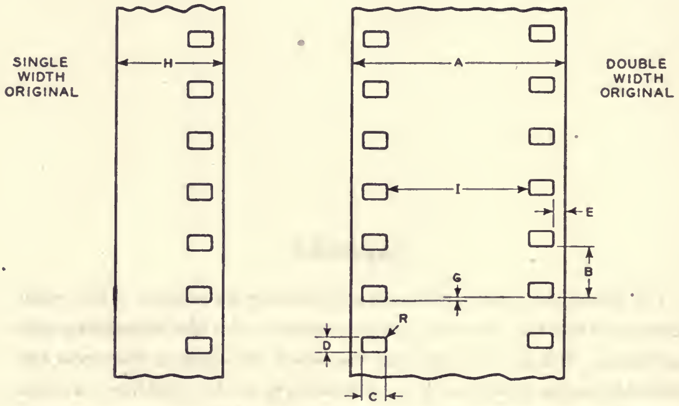
American Standard
Cutting and Perforating Dimensions for
8-Millimeter Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.17-1947
Revision of
Z22.17-1941



Dimensions	Inches	Millimeters
A	0.629 ± 0.001	15.98 ± 0.03
†B*	0.150 ± 0.0005	3.810 ± 0.013
C	0.072 ± 0.0004	1.83 ± 0.01
D	0.050 ± 0.0004	1.27 ± 0.01
†E	0.036 ± 0.002	0.91 ± 0.05
†G	Not > 0.001	Not > 0.025
H‡	0.314 ± 0.0015	7.98 ± 0.04
†I	0.413 ± 0.001	10.490 ± 0.025
L§	15.000 ± 0.015	381.00 ± 0.38
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.17-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.17-1941.

‡In the slitting of double-width film after processing, the cut shall be made within 0.002 inch of the center line.

§This dimension represents the length of any 100 consecutive perforation intervals.

American Standard
Cutting and Perforating Dimensions for
8-Millimeter Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.17-1947
Revision of
Z22.17-1941

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the film, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

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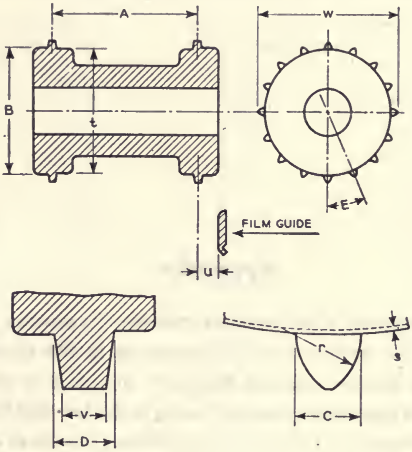
Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important. This is one of the reasons for the method of specifying uniformity in dimension B.

American Standard Dimensions for 16-Tooth 35-Millimeter Motion Picture Projector Sprockets

ASA
Reg. U. S. Pat. Off.
Z22.35-1947
Revision of
Z22.35-1930

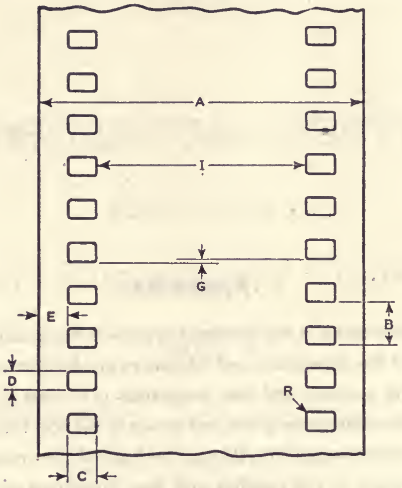


	Feed Sprocket		Intermittent Sprocket		Take-up (Hold Back) Sprocket	
	Inches	Millimeters	Inches	Millimeters	Inches	Millimeter
A	1.097±0.001	27.86±0.03	1.097±0.001	27.86±0.03	1.097±0.001	27.86±0.0
†B	0.943±0.001	23.95±0.03	0.943±0.001	23.95±0.03	0.932±0.001	23.67±0.0
C	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.00}_{-0.05}$	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.00}_{-0.05}$	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.0}_{-0.0}$
D	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.00}_{-0.05}$	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.00}_{-0.05}$	$0.055^{+0.000}_{-0.002}$	$1.40^{+0.0}_{-0.0}$
E	22 Degrees 30 Min±1.5 Min		22 Degrees 30 Min±0.75 Min*		22 Degrees 30 Min±1.5 M	
			Suggested Dimensions			
r	0.077	1.96	0.077	1.96	0.077	1.96
s	0.004	0.10	0.004	0.10	0.004	0.10
t	0.935	23.75	0.935	23.75	0.922	23.42
u	0.139	3.53	0.139	3.53	0.139	3.53
v	0.040	1.02	0.040	1.02	0.040	1.02
w	1.045	26.54	1.045	26.54	1.032	26.21

*The accumulated error between any 2 teeth not to exceed 4 minutes.
†This dimension is the only change from the 1930 edition.

American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock*

ASA
Reg. U. S. Pat. Off.
Z22.36-1947
Revision of
Z22.36-1944



Dimensions	Inches	Millimeters
A	1.377 ± 0.001	34.98 ± 0.03
†B	0.1870 ± 0.0005	4.750 ± 0.013
C	0.1100 ± 0.0004	2.794 ± 0.01
D	0.0780 ± 0.0004	1.98 ± 0.01
†E	0.079 ± 0.002	2.01 ± 0.05
†G	Not > 0.001	Not > 0.025
†I	0.999 ± 0.002	25.37 ± 0.05
L‡	18.70 ± 0.015	474.98 ± 0.38
R	0.020	0.51

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*This film is used for motion picture prints and sound recording.

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.36-1944.

‡This dimension represents the length of any 100 consecutive perforation intervals.

American Standard Cutting and Perforating Dimensions for **35-Millimeter Motion Picture** Positive Raw Stock	ASA Reg. U. S. Pat. Off. **Z22.36-1947** **Revision of** **Z22.36-1944**

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the film, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness of projection.

Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important.

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Donald E. Hyndman, *Television*
Paul J. Larsen, *Television Projection*
W. W. Lozier, *Lighting*
Charles S. Perkins, *Acoustics*
Henry Anderson, *Safety and Maintenance*
Seymour Seider, *Ventilating and Air-Conditioning; Promotional Display*

PUBLICITY
Harold Desfor, *Chairman*
Leonard Bidwell
Don Gillette

REGISTRATION AND INFORMATION
W. C. Kunzmann, *Chairman*

LUNCHEON AND BANQUET
Lester B. Isaac, *Chairman*

HOTEL AND TRANSPORTATION
Oscar F. Neu, *Chairman*

MEMBERSHIP AND SUBSCRIPTION
Lee E. Jones, *Chairman*

PROJECTION PROGRAM—35-MM
H. F. Heidegger, *Chairman*
Assisted by Members of the New York Projectionists Local 306

PROJECTION PROGRAM—16-MM
M. W. Palmer, *Chairman*

PUBLIC ADDRESS SYSTEM
Harry B. Braun, *Chairman*

SCIENTIFIC AND EDUCATIONAL EXHIBIT
Robert T. Kenworthy, *Exhibit Manager*
W. W. Simons, *Chairman*
Sidney B. Moss
J. W. Servies

TENTATIVE TECHNICAL SESSIONS

Monday, October 20, 1947

9:00 A.M.–10:00 P.M. PENN TOP
Scientific and Educational Exhibit.

9:00 A.M. HOTEL 18TH FLOOR
Registration. Advance sale of Luncheon and Banquet Tickets.

10:00 A.M. SALLE MODERNE
Business Session.

11:00 A.M. SALLE MODERNE
Theater Engineering Session, "Introduction".

12:30 P.M. GEORGIAN ROOM
Get-Together Luncheon (Eminent Speakers).

2:00 P.M. SALLE MODERNE
Theater Engineering Session, "Physical Construction". (Regular, Prefabricated, and Drive-In Theaters).

8:00 P.M. SALLE MODERNE
Theater Engineering Session, "Auditorium Design".

Tuesday, October 21, 1947

9:00 A.M.–10:00 P.M. PENN TOP
Scientific and Educational Exhibit.

9:00 A.M. HOTEL, 18TH FLOOR
Registration, Advance Sale of Banquet Tickets.

10:00 A.M. SALLE MODERNE
General Technical Session.

2:00 P.M. SALLE MODERNE
Theater Engineering Session, "Floor Coverings".

8:00 P.M. SALLE MODERNE
Theater Engineering Session, "Television".

Wednesday, October 22, 1947

9:00 A.M.–5:00 P.M. PENN TOP
Scientific and Educational Exhibit.

9:00 A.M. HOTEL, 18TH FLOOR
Registration, Advance Sale of Banquet Tickets.

10:00 A.M. SALLE MODERNE
General Technical Session.

2:00 P.M. SALLE MODERNE
Theater Engineering Session, "Lighting".

7:15 P.M. GEORGIAN ROOM (Reception Foyer)
Cocktail Hour for Holders of Banquet Tickets.

8:30 P.M. GEORGIAN ROOM
62nd Semiannual Banquet and evening for social get-together (dancing and entertainment). Tables may be reserved at the Registration Headquarters prior to noon of October 22.

Thursday, October 23, 1947

9:00 A.M.–10:00 P.M. PENN TOP
Scientific and Educational Exhibit.

OPEN MORNING

2:00 P.M. SALLE MODERNE
Theater Engineering Session, "Acoustics".

8:00 P.M. SALLE MODERNE
Theater Engineering Session, "Television".

Friday, October 24, 1947

9:00 A.M.–5:00 P.M. PENN TOP
Scientific and Educational Exhibit.

10:00 A.M. SALLE MODERNE
General Technical Session.

2:00 P.M. SALLE MODERNE
Theater Engineering Session, "Safety and Maintenance".

8:00 P.M. SALLE MODERNE
Theater Engineering Session, "Ventilating and Air-Conditioning; Promotional Display".

GENERAL INFORMATION

Hotel Reservations and Rates

The management of the Hotel Pennsylvania, 33rd Street and Seventh Avenue, Convention Headquarters, extends to members and guests of the Society of Motion Picture Engineers the following per diem room rates, European plan:

Room with bath, 1 person: $4.00, $4.50, $5.00, $5.50, $6.00, $6.50, $7.00.
Room with bath, 2 persons, double bed: $6.00, $6.50, $7.00, $7.50, $8.00, $8.50, $9.00.
Room with bath, 2 persons, twin beds: $7.00, $8.00, $8.50, $9.00, $10.00, $11.00, $12.00.
Parlor Suite, for 1 or 2 persons: $13.50, $14.50, $16.50.

NOTE: Room accommodations must be booked early and direct with Frank A. Morse, front office manager, Hotel Pennsylvania, and prior to October 15. No rooms will be assured or available unless confirmed by the hotel management.

Registration

The Conference Registration Headquarters will be located on the 18th floor of the hotel adjacent to the Salle Moderne, where all business and technical sessions will be held during the five-day conference. Members and guests must register to attend sessions and the Exhibit. The fee is used to defray Conference expenses.

Transportation

Members and guests who contemplate attending the 62nd Semiannual Convention and Theater Engineering Conference in New York should consult their local railroad, Pullman, and airline agents at least 30 days in advance of departure date regarding effective schedules and rates.

SMPE Get-Together Luncheon

The usual Get-Together Luncheon will be held in the Georgian Room, on Monday, October 20, 1947, at 12:30 P.M.

The luncheon program and eminent guest speakers will be announced later. Guaranteed seating at the luncheon will be assured only if tickets are procured prior to October 17, 1947. Assist the Committee and hotel in providing accommodations by complying with this request.

Informal Banquet and Dance

The SMPE 62nd Semiannual Informal Banquet and Social Get-Together will be held in the Georgian Room of the Hotel Pennsylvania on Wednesday evening, October 22, at 8:30 P.M. (Dress optional.)

A Cocktail Hour for holders of Banquet tickets will be held in the Georgian Room (Reception Foyer) preceding the Banquet from 7:15 to 8:15 P.M.

Banquet tickets should be procured and tables reserved at the Registration Headquarters prior to noon on October 22. The Banquet program will be announced later.

Luncheon and Banquet tickets may be procured in advance of the dates of these functions through the Society office or through W. C. Kunzmann, Convention Vice-President, who will be at the Pennsylvania a week prior to the opening date.

NOTE: All checks or money orders issued for registration fee and luncheon or banquet tickets should be made payable to *W. C. Kunzmann, Convention Vice-President,* and not to the Society.

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

28, 6 (June 1947)

Magnetic Tape Recording (p. 199)

Painting with Technicolor Light (p. 200) H. A. LIGHTMAN

The Cinema Workshop. Special Effects (p. 208) C. LORING

A New Series of Camera Lenses for 16-Mm Cinematography (p. 210) W. B. RAYTON

International Photographer

19, 6 (June 1947)

The Baltar Series of Lenses (p. 12) A. E. MURRAY

Zoomar Lens Makes Debut (p. 22) R. WINCKLER

International Projectionist

22, 6 (June 1947)

Acetate Stock to Supplant Nitrate (p. 5) H. B. SELLWOOD

Television Today and Its Problems (p. 8) A. N. GOLDSMITH

Tele-Tech

6, 6 (June 1947)

Color Television for Theatres (p. 44) H. G. SHEA

Embossing Type Sound Recorder (p. 55)

Bibliography of Disc Recording (p. 73) A. JORYSZ

Radio News

38, 1 (July 1947)

The Recording and Reproduction of Sound. Pt. 5 (p. 55) O. READ

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CORRECTIONS

The JOURNAL of the SMPE wishes to correct the following errors which appeared recently in its pages.

* * *

At the bottom of page 311, in the April, 1947, issue, the following statement was made: "Finally, at Beaconsfield will be housed the Central Film Library." The British Information Services has brought to the attention of the Editor that the address of the Central Film Library continues to be: Imperial Institute, South Kensington, London, S. W.7, England.

* * *

On page 418 of the May, 1947, issue of the JOURNAL, alongside of the heading "July 1928", there appears this statement. "Paramount began recording in Hollywood on a temporary channel and first used sound in their picture 'Warming Up', with Richard Dix." In a letter to the Editor, Mr. Walter F. Wanger states, "I was in charge of production at Paramount at that time and we did not begin recording in Hollywood but recorded on disks at the Victor Talking Machine Plant in Camden, N. J."

JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

Vol 49 SEPTEMBER 1947 No. 3

CONTENTS

Indexes to the semiannual volumes of the JOURNAL are published in the June and December issues. The contents are also indexed in the *Industrial Arts Index* available in public libraries.

JOURNAL

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JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

Vol 49 SEPTEMBER 1947 No. 3

RETOOLING FOR EDUCATION 1948*

W. A. WITTICH**

Summary.—*The problem of educational responsibility is outlined, particularly the aspects concerned in the enormous increase in scope of man's environment during the past hundred years. The means for becoming acquainted with this expanded environment are discussed and the place of audio-visual teaching aids in this broad over-all picture is examined.*

It has been said that the primary responsibility for those who assume assignments in our classrooms and on our administrative staffs is to organize the experiences of our environment so as to allow young learners to become acquainted with those things which lie about them and among which they live as methodically, effectively, and as realistically as possible. Thus our primary responsibility for education is to acquaint young learners with their environment—to lead the children who come under our direction through a series of experiences which will allow them to become informed completely about two aspects of the world in which they live: First, those things and experiences which are included in the environment which nature has provided; and second, those plans, those cultural patterns, and those problems which go to make up the man-made or social environment.

This may seem an oversimplification, but when we analyze it, all of man's relationships are in terms of his ability first to understand those things which exist within these two environmental spheres. On the basis of his complete understanding of these, he attempts to arrive at a course of action which will allow him to experience happiness, peaceful cultural relationships, and a high standard of living. In contrast to this, we as adults have periodically allowed ourselves to be sent crashing into the ruins of great world conflicts. This experience cannot and must not reoccur tomorrow.

* Presented Apr. 23, 1947, at the SMPE Convention in Chicago.

** Director, Bureau of Visual Instruction, University of Wisconsin, Madison.

Today those of us who are searching for means of acquainting our young people with formal educational experiences are confronted with problems which did not exist a century ago, but which today are being placed squarely in the laps of educators. Today education is the sole remaining social agency capable of assuming this responsibility. That education is today being the recipient of this heretofore unrealized social responsibility is evidenced on many fronts.

First, in the report of the United States Chamber of Commerce we have an outright acknowledgment that in those sections of the country where good educational systems exist, there, too, exists a high standard of living. Second, from this same source we have the acknowledgment that in those communities where a good system of public education exists, there, too, exists a profitable market for the commodities which man produces. Third, for the first time in our history has the president of the United States formally announced through his radio talks that upon the assumption by educational agencies of the responsibility for world enlightenment lies a last remaining hope for peace and for a world order in which we can seek to attain desirable social outcomes.

These three evidences from sources, heretofore known to be sometimes antagonistic and certainly disinterested toward the place which formal education occupies, are evidences of a growing popular trend, and a change in attitude toward public education. Why has this occurred?

Allow us to see how the role of education has changed over the last hundred-year period. One hundred years ago what was the "community" and what was the responsibility of education to that community? Many of us come from southern states in which the county government division was formed on the basis of the distance a man could ride on horseback during a one-day period. In the north, where hilly terrain predominated, the local unit of government of the township was frequently determined by the distance a man could see—the rim of the valley or the land bounded by rivers or hillcrests. Within these limited communities, the school accepted its responsibility—its responsibility for the teaching of arithmetic to the rule of three, of writing, and of reading—and as soon as the child could be turned over to an apprentice situation, he was there to learn for himself, in the shortest possible time, how to earn a living within the community in which he was reared. That was education a hundred years ago. That was the community that education served.

Without going any farther to trace the trend from that time to the present, examine briefly what the problems of an enlarged world-wide environment mean to the responsibility which education must accept today. Today when we speak in terms of United Nations, when we speak in terms of girdling the globe as Reynolds did in 72 hours, when we speak in terms of rocket missiles which will accomplish the transit of the oceans in a matter of minutes, when we speak of communication systems undreamed of a decade ago, we know that the responsibility for man understanding his environment is no longer confined to the valley, to the county, or to the township, but rather to the whole world. Today's educational responsibility encompasses a global environment. Today's school responsibility is beyond all previous comprehension. It is so vast that today's society is gladly willing that public education assume a role which it has never been asked to assume in the past. Thus, we in education find ourselves members of the last remaining social agency capable of approaching this tremendous problem.

Let us stop to examine the tools with which we have to work, the personnel which staffs our school, and ask ourselves, "Are we up to the problem?" Very largely, our teaching staffs comprise those persons who were with us ten years ago. Very largely, our curriculum plans are unchanged. Unchanged, too, is the instructional equipment and the educational tools with which we have to work. Our responsibilities have leaped ahead in inaccountable terms, but the tools with which we work are dragging pitifully. In the words of Ernest Horn of Iowa, "90 per cent of our classroom learning experiences are confined to a textbook." In the field of geography we are still clinging to a course of study which was developed twenty years ago and which does not take into consideration an understanding of parts of the globe that have recently leaped into prominence during the last five-year period. The problem remains, what are we going to do? What tools can we locate?

Ten years ago, even today, the philosophic argument still remains, "Should teachers be satisfied to pass along to young learners an historical accumulation of information out of the past, or should teachers be allowed to teach of the present and plan for the future?" I believe that the last is our role.

Today this country is the single remaining first-line political and economic power. This country alone must assume full responsibility for the rehabilitation of the entire world. The school certainly must

misunderstood. Probably the best division of the film medium is into the two categories of theatrical (for showing in theaters) and nontheatrical (for showing in schools, churches, civic organizations, and union halls). Theatrical releases are designed primarily for entertainment and are not our concern here. Our concern is with the non theatrical field, with governmental, industrial, and sponsored or unsponsored classroom films. This is a complex, vital new means of communication. In prewar America there were two decades during which we felt our way in the field. In general, films were dull and technically poor. There were few projectors for nontheatrical showings. School budgets did not include funds for visual tools and equipment. With a limited and unpredictable market, a dozen reputable firms made low-cost films for schools, and a dozen dozen industries advertised themselves and their products by objectionably sponsored films. But it was not an established industry. Distribution outlets were wholly inadequate. It was a formative period, with isolated groups toying with an idea whose potentialities were neither recognized nor exploited.

The war brought films to a position of significance because they were the only logical way to speed up the training of our vast numbers of army and navy personnel; so suddenly taken from civilian life and fashioned into military men. All governmental and civilian agencies united to produce a flood of training and propaganda films. Thus an emergency brought proof to what had before been supposition; the film medium came into its own as a teaching weapon.

The facts about use of films in education are well known. Out of the war, in addition to this knowledge, came a multitude of men and women trained in the field, sold on its future, and eager to make films their postwar vocation. And what do they find?

We as a nation of civilians are not ready either to make or to use films in the manner of a nation geared for war. Those of us in the nontheatrical field entered the era after the war full of hope; now, more than two years later, certain truths stand out. The school market has remained a fairly static thing. With a few heartening exceptions, budgets are low. There are only a few thousand projectors in use in American schools. The wealth of talent trained in war has formed literally hundreds of production companies, most of them operating with limited capital, and they have found (*a*) that an investment in an educational film is a long-range and uncertain thing, and (*b*) that industrial and governmental sponsors are difficult to sell.

Distribution, the largest single handicap, is uncharted and inadequate. Poor distribution means a low print sale; a low print sale means a reduced production budget; a reduced production budget means technical excellence far below that of theatrical releases. And so the cycle continues, with schools and other consumers waiting for a better product, and the producer unable to make a better product until he has a larger potential market.

These considerations are not in any sense an indictment of the field or its potentialities, nor are they a reflection of waning enthusiasm on the part of our company. On the contrary, we are more positive than ever that the nontheatrical film will play a significant role in shaping the postwar world.

There are corresponding encouraging things. Across the country educators are meeting and working to bring use of visual aids to a prominent position in schools. Manufacturers are perfecting low-cost, lightweight, easy-to-operate projectors. Foundations and industries are sponsoring more and more films in the public interest. Scientific research, such as that conducted under the auspices of the Motion Picture Association, is determining what kinds of film are needed and what kinds of film teach best. New techniques are enlarging the scope of the motion picture. Labor is beginning to use film as a means of expressing its point of view. The church, too, is making use of films to help retain its position in a changing world. The Department of State, the Department of Agriculture, the Attorney-General—these and many more governmental agencies are making films for national and foreign distribution. New fields are being opened—social hygiene, medicine, psychology. These things make us know that the job is worth doing, and worth doing well.

Ours is an important responsibility. It is obvious to even a casual observer of fourth-decade twentieth-century living that much must be done, and soon, if the democratic way of life is to survive. The danger to our country lies not so much in the encroachment of various "isms" and ideologies as it does in our failure, individually and collectively, to understand and participate actively in our government. We have fallen into the terrifying complacency of letting others think for us. This is because we are not educated to our responsibilities. America began with the idea of giving to every man an equal chance, founded on a belief that the majority of common men, *properly informed*, will choose and enforce the right kind of governmental action. Thomas Jefferson stated it this way:

> "I know of no safe depository of the ultimate powers of society but the people themselves; and if we think them not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it from them, but to increase their discretion by education."

The need, then, is for mass education. Education is largely a matter of communication. Film is best suited for this communication of ideas because it best combines four essentials: it is simple, it is fast, it is universal, it is democratically sound. As George Bernard Shaw wrote, "The number of people who can read is small, the number of those who can read to any purpose is smaller, and the number of those too tired to read after a hard day's work is enormous. . . but all except the blind and the deaf can see and hear."

What kind of films? How can it be done? What is the next move? The answer lies in our ability to agree on one simple premise. I believe that it is vital to educate Americans so that they will participate actively and intelligently in a democratic government. If you agree with me, we have a starting point. I recognize the importance of using films to teach fundamentals of arithmetic and science and social studies, to advertise our products, to train our personnel, to build good will. These things are all significant. But we must place the emphasis on films which. . . on all levels, to all peoples, in all areas. . . teach citizenship—the kind of citizenship which results in the average American's being an informed, tolerant, active participant in the affairs of his country and his world.

Here are some specifics, film subjects which should be converted into motion pictures for America to see and hear: Housing: Juvenile Delinquency. Healthy Daily Living. Child Training. How Your Vote Is Reflected in Laws. Family Relationships. Management and Labor. Household Management. Marital Hygiene. Government in Local and World Affairs. Racial Equality. International Relations. There are a hundred such subjects and they will not be made into films soon enough, or well enough, unless the urgency of our crisis is brought home to those individuals, groups, industries, foundations, and governmental agencies which can invest America's money in America's future.

We sincerely believe that unless we in the motion picture industry combine our efforts with those of others working to educate America, we may find that there will be no democracy tomorrow, and, for some of us, no tomorrow at all.

PSYCHOLOGY OF THE SOUND FILM*

L. MERCER FRANCISCO**

Summary.—*As an educational instrument the sound film is particularly effective for influencing people in groups, bringing to bear factors in social as well as individual psychology: social facilitation, the impression of universality, and prestige. The physical conditions under which its message is received and the absorption of the audience in the continuity of the screen story polarize the attention almost to the degree of hypnosis, with corresponding effect upon the subconscious and memory. Little intellectual effort is required to comprehend the meaning of visual-action images when coordinated with spoken words. The appeal to the emotions is equally strong through the control of empathic responses by means of meaningful real-life situations dramatically portrayed. Self-identification by the audience with the screen characters and subject matter provides vicarious experience, short-cuts the learning process, and arouses the will to believe or to act.*

Signs of the times indicate that the engineer is beginning to show some concern over the social implications of his inventions and to feel some responsibility for them.

Dr. Lee de Forest recently registered a vigorous protest against the abuses which his great invention, radio, has suffered at the hands of its commercial exploiters.

The Association of Atomic Scientists has made it plain that they do not feel that their responsibility for the atomic bomb ended with their invention of it. They have become quite vocal in their insistence that atomic energy be applied to social advancement rather than to the destruction of civilization.

The first note made of the misuse of the engineer's talents was recorded by Thorstein Veblen twenty-six years ago in a trenchant little book, *The Engineers and the Price System.* Few engineers seemed to have paid any attention to it, however, until 1946, when John Mills, of the Bell Telephone Laboratories, published *The Engineer in Society.* How many engineers have read Mills' provocative book remains to be seen.

THE INTERESTS OF THE MOTION PICTURE ENGINEER

The motion picture engineer has apparently shown no more concern over the uses to which his products have been put than other technologists, in spite of the fact that the motion picture has been

* Presented Apr. 23, 1947, at the SMPE Convention in Chicago.

** Francisco Films, Chicago, Ill.

more severely criticized for the ill effects it has had upon our culture and mores than any other invention. Whole volumes of criticism have been published and research foundations have devoted their energies to studying the baneful influence of motion pictures upon attitudes, social life, and behavior patterns.

In view of the fact that the motion picture, particularly the sound film, ranks with the invention of movable type, the telephone, the radio and the automobile, as an instrument of communication which has had far-reaching effects upon our way of life, it behooves the technologist working with the medium to extend the range of his interest in it beyond the confines of the engineering laboratory into the realm of the uses of the film.

THE SOUND FILM BEYOND THE FIELD OF ENTERTAINMENT

To date, the motion picture has been used almost entirely as an entertainment device, for that is where the "big money" has lain. Within the past decade, however, the application of the filmic medium to other ends of communication—education, instruction, and propaganda, in its positive sense—indicates that the future usefulness of the medium in this field may transcend in importance its application to entertainment. The social scientist, particularly the social psychologist, has discovered unequaled powers in the sound film to influence the minds and emotions of people for better or for worse.

THE CREATION OF SOUND FILMS A SPECIALIZED ART

The producers of sound films for commercial and educational purposes are probably better acquainted with the psychological impact of the sound film and the techniques for producing desired attitudes and responses with it, than any other factors in the motion picture industry. In the creation of sound films for educational, sales, or training purposes, they begin with a study of the audience, the occasion, the objective of the film, and the idea content for it, and they employ the various elements of the medium to create the desired impression upon the mind and nervous system of the audience under the given conditions of the screening and of the audience's mental "set" toward the film's subject matter.

To appreciate fully the significance of this approach, try designing a sound film. It will be quickly realized that in the sound motion

picture something more is involved than cameras, film stock, and sound channels. Probably the most important lesson that the Armed Services learned in their vast film program was that the creation and production of sound films had best be left to those who best understand the medium as an instrument of expression; therefore as a tool for the shaping and control of psychological factors. George Arliss, whose experience on the stage, in silent motion pictures, in sound movies, and in writing for publication, qualified him to speak, vividly characterized the uniqueness of the sound film as an art form. He said that there is a greater difference between the sound motion picture and the silent motion picture, as a medium of expression, than there is between the silent motion picture and the printed page. He averred that he had to learn to act all over again when sound came into pictures.

INFLUENCING PEOPLE IN GROUPS

The sound film is, by its very nature, a medium for influencing minds *in groups*, whereas other mediums of communication, such as the printed page, posters, and radio, influence minds as individuals. The reader of a magazine or the listener to a radio program reacts to the message that reaches his mind as an individual, whereas the member of a sound-film audience reacts to the film as a unit of a co-acting group. Social psychology, as well as individual psychology is, therefore, at work in the film audience.

"SOCIAL FACILITATION" AND THE "IMPRESSION OF UNIVERSALITY"

Consider, for a moment, the psychology of the audience situation of the sound film. The various members of the audience are seated in rows, all facing toward a common source of sensory impressions. This regimentation of their bodies tends to induce a corresponding regimentation of their minds. In the regimented film audience, "social facilitation" is at work; that is to say, the reactions of one member of the group are "sensed" by his neighbors and tend to spread from one to the other, like a contagion. A related phenomenon results—the "impression of universality", or the conviction that what is true for one individual is true for another. This is a vital factor in credibility. Of course, social facilitation and the impression of universality prevail in almost all audiences, but not to the degree that they do in the sound-film audience, because of other factors in the medium which will be discussed later.

THE PRESTIGE OF THE SOUND FILM

The sound film, as a medium of communication, has *prestige*, an important quality in any medium. Its prestige is not derived solely, however, from its association with Hollywood and the glamour of sound-film-production technology. Most of its prestige is derived from the unique qualities inherent in the medium itself, particularly the intensely concentrated attention it demands, which will be referred to later. Prestige is also derived from the *occasion* of the film showing: the audience has assembled especially to see and hear the film and everybody submits to its dominating influence. The *authority* of the spoken word and the vivid visual-action images that are burned into the mind, add to the prestige of the medium. There is no other medium of expression—the largest, most popular magazine, the world's largest spectacular, or the biggest national network—that can match the impact of the sound film in so far as the prestige of the medium is concerned.

THE "POLARIZATION" OF ATTENTION

There are psychological factors in the conditions under which the sound-film message is received that are no less important than those of the audience situation. Consider the fact of the darkened room, with all extraneous sounds shut off, in which the sound film does its work. The two primary sense organs—those of sight and hearing—are focused on a single source of sensations: the screen and the loudspeaker. The effect created is akin to that of hypnosis, for, as you know, to put a person "out", the hypnotist induces him to focus the attention of his eyes on a single point while he drones something into the subject's ears. The sound film, likewise, "polarizes" the attention to almost the same degree and induces in the subject a state of suggestibility similar to that induced by the hypnotist.

Scientific proof of the intensity of the concentration of the attention of the sound-film audience to the influence of the screen and loudspeaker has been provided on many occasions, by many experimenters. They have flashed bright lights and rung bells to distract the attention of the sound-film audience and have taken pictures of the audience's reactions. These have shown nothing but momentary glances away from the screen. The mind that "wanders" along any paths except those directed by the screen story is almost unknown in the sound-film audience. The salesman or propagandist who wishes

to *hold* attention to his sales message can do it beyond peradventure in this dynamic medium. "Spellbound" is not too strong a word for describing the attention-compelling power of the sound film.

ATTENTION-COMPELLING POWER OF THE PRESENTATION

The sound film sustains attention for other reasons than the physical conditions of the screening in the darkened room with extraneous sounds shut out. The medium itself grips the attention through the "flow" of the ideas it presents. It presents visual-action images in a "stream-of-consciousness" manner, requiring virtually no intellectual effort for comprehension. If the presentation is in the form of a drama unfolding in the words and actions of screen characters with whom the audience can identify themselves readily, then, indeed, the attention is spellbound, for the audience becomes "lost in the story". Psychologists say that the mind cannot concentrate on any fixed object longer than about seven seconds. In the sound motion picture there is no fixed object; even in the sound slide film, if it is properly conceived, there is a change of picture on the screen about every seven seconds, so the eye simply cannot stray without missing something, and the mind cannot wander.

CLARITY ACHIEVED IN VISUAL-ACTION IMAGES

One might, conceivably, be entranced by a continuously moving object and still not understand it. What can be said, therefore, as to the impact of the sound film upon the mind? This: that it makes its idea content crystal clear, because it presents ideas in visual-action images of the very type which is believed to be involved in thought processes themselves. The Chinese made this point thousands of years ago and expressed it in what has become a cliché in the field of the graphic arts in "one picture is worth ten thousand words". The great significance of this point in the educational field has recently been brought out in the work of the semanticists. They have discovered that "verbalism" is the most serious defect of our educational methods and they see in the sound film a means of correcting it.

CLARITY IN SPOKEN LANGUAGE

The importance of words should not be underrated, for words, rather than pictures, are the symbols of thought. A film without words is relatively meaningless. In every effective sound film the

idea content is presented primarily in words and secondarily in pictures; the pictures supplement, complement, define, and clarify the meaning of the words. But the words of the sound film are *spoken* words. Spoken language is the kind that all of us use every day, all day long, and that all of us hear all the time. They are readily comprehended, assuming they are within the range of our listening if not of our speaking or writing vocabulary. In fusing these two primary factors in clarity—visual-action images and spoken words—the sound film reaches the intellect more readily, with less effort, and more impressively than does any other method of expression.

THE APPEAL TO THE EMOTIONS THROUGH SOUND

People do not, however, think with their minds alone. The behaviorist insists that they also think with their viscera and the neurologist that their endocrine glands are involved. Everyone will admit that people *feel* more than they *think* and that the appeal to the emotions is often of more importance than the appeal to the mind. The impact of the sound film on the emotions is, if possible, even greater than its impact on the mind. Attitude, or "mental set", is the determinant of mental activity, and it is the product of the emotions. The recent rapid strides that have been made in scientifically pretesting the appeal of sound films is based upon measurements of emotional responses, by instruments something similar to the lie detector.

Probably the most important element in the sound film influencing the emotions is its sound. The effect of sound upon the feelings is most readily appreciated in the field of music. "Music hath charms to soothe the savage breast." That sound affects the feelings or emotions, while sight appeals to the mind, has always been an accepted fact. The birth of Christ was announced to the Wise Men of the East—men of intellect—through a star in the heavens, a visual symbol, whereas to the shepherds feeding their flocks—presumably simple-minded folk—it was heralded through angels' voices singing. When the history of music is written a generation from now, the contributions which the sound film has made to it will be better appreciated than it is today. Every script writer, even of commercial films, knows what music can do to advance his story and to induce the desired attitude in the film audience. Along with music, of course, is included "sound effects"; they help the sound film, as one writer puts it, to "create the fury as well as the battle, the song as well as the lark".

EFFECT OF DRAMATIC SCENES AND "EMPATHY"

The impact of the sound film upon the emotions is manifest in other elements, however, as well as in its music and sound effects. The action of screen characters involved in tense, emotional situations, induce corresponding emotions in the audience.

The psychologists have a word for this phenomenon of inducing emotions in one individual through portraying emotions in another. It is "empathy". It is your empathic responses which make you almost push your neighbor off his seat at a football game, when your own body leans rigidly in the direction of the line plunge of your own team. It is empathy that makes your muscle tensions follow those of the screen character in the dramatic portrayal.

VICARIOUS EXPERIENCE THROUGH SOUND-FILM STIMULI

So strong is the appeal of the sound film, through both its sound and its visual-action images, to the emotions, that it often is the equal of real-life experience itself in intensity. Indeed, there are films in which the screen-presented story seems even more real than real life! Imagine what that means in propaganda, selling, public relations, education, and training. It means that, with the sound film, you can groove or condition the nervous systems of people, in a directed, controlled manner, almost as well as experience itself! You can provide them with vicarious experience in the form of muscle tensions, nervous responses, blood pressure, respiration, and all the acitivities of the sympathetic nervous system by controlling the secretions of their endocrine glands through the stimulus of the sound film. What other medium of communication can even approach the sound film in this power?

IMPRESSION OF THE SOUND FILM ON MEMORY

Earlier in this article reference was made to the "polarization" of attention which the sound film induces, by way of the darkened room with extraneous sounds shut out and the gripping hold of the screen story. This phenomenon has profound effects upon the *memory*. Psychologists tell us that there can be no learning without memory. Sales or educational material that is presented in the sound film penetrates into the depths of the subconscious mind of the individual who is "lost" in its story, and every item of the material is surrounded by a rich background of associated materials which serve to aid recall

long after the sound-film showing. Having provided both visual images and aural impressions with the material, recognition of the recalled elements is instant and easy.

Proof of the lasting effects of the sound film upon the memory has been provided in abundance by many kinds of tests, some of them revealing facts hard to explain. For example, in some instances, material from a sound film is more readily recalled several months after exposure to it than it is twenty-four hours or even immediately afterward!

REPETITION TO BE AVOIDED IN SOUND FILMS

Advertisers who have been told that anything said on the radio has to be repeated at least three times in order to make it sink in, are going to have to learn restraint in their commercials when they get into television or when they use sound motion pictures—unless to irritate is their purpose. They are going to find that the less often they say what they have to say about their product in the sound film, the more favorable impression they will create; indeed, they may not have to say anything, if the pictures they employ say it without words. They will also have to learn that the screen audience abhors repeated pictures. It responds against subject matter with even more intensity than it responds in favor of it, a fact that some sound film producers know but that many users have yet to learn.

It can be appreciated readily how markedly the sound film differs, in its psychological factors, from other mediums of expression, the printed word, the radio, the lecture, and the stage. Students of social psychology, of educational problems, of propaganda, of public relations, and of training procedures, are fast recognizing the sound film as the most potent instrument for accomplishing their objectives that has been developed in the field of communication.

TRAINING-FILM PRODUCTION PROBLEMS*

REID H. RAY**

Summary.—*The production of motion pictures for training presents distinct reasons for techniques different from ordinary documentary or factual film methods. This is true whether the visual aid is produced during the stress of wartime requirements, or for training in industry, or educational fields in normal times. There are problems in (1) set construction, (2) camera angles, (3) selection and rehearsal of talent, and (4) editing tempo. After producing nearly 100 training films, the author has a background to present the reason "why" for the distinct pattern followed in training-film production.*

More than 1900 motion pictures for training purposes were made by industrial-film producers in four years; an unprecedented era for the commercial motion picture. These 1900 subjects were written, produced, and released between 1941 and 1944. They were produced for training the military forces and training within industry, and do not include films made by Hollywood or the motion picture service divisions of the military forces.

It was proved that the use of visual methods speeded up training as much as 34 per cent, as well as doing a more thorough job. During our war years, as never before, motion pictures helped do a job faster and better, and were a contribution, in no small way, to the war effort.

Because there has been a continued use of training, educational, and documentary films throughout the world, the discussion of problems in production appears timely.

SET CONSTRUCTION

In a training film, the minimum number of sets should be used. It is unnecessary to motivate the action by location changes as in the entertainment picture. The training film should be a presentation of one subject, treated in logical sequence, with one simple location or set, if possible. To cover too much subject matter in one film is dangerous. The trainee can retain the technique much easier if it is presented in an unpretentious manner.

The sets must be authentic. There is no need for highly stylized,

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** Reid H. Ray Film Industries, Inc., St. Paul 1, Minn.

dramatic, or tricky sets for photographic effects. If a training film on how to operate a horizontal milling machine is to be made, the set should look like a real machine shop. Nothing should be included in the set to distract the attention of the trainee while viewing the film. The trainee may have spent several years in a machine shop as an apprentice and if the film is to "teach", it has to have every appearance of genuine authority. The film must *show* as well as *speak* the language of the machine shop. A training film needs no entertainment to do its job thoroughly. It is a good practice to visit several factories, before constructing sets, to be sure that the set which will appear on the screen will look like a real shop, and not a motion picture set. Often a set can be built in a factory around the machine to be used as the "prop" for the film. In these instances simplification of background is important.

In a series of 20 electrical training films, "live" sets had to be used. These sets represented new and old houses which were to be wired. In the "new-house" wiring films, the rooms of the house were in the unfinished building stage. There were two-by-four room partitions, rough flooring, siding, and cement building blocks for foundations. In the old-house sets, there were finished walls complete with lath, plaster, and wall paper. The two by fours were 16 inches on center, and the headers in the walls were properly spaced, because the problems were those actually found on electrical-installation jobs.

It was necessary to build a full-scale, two-story, one-room house in the studio for the films on wiring old houses. It was quite impossible to show authentically the work required in a one-story conventional set. One sequence illustrated the method of tearing up the upstairs floor and running cable under the floor for the first-floor ceiling fixture. There, again, the set had to have lath, plaster, rough and finished flooring complete; yes, and even old-style wall paper used 20 years ago.

A similar technique should be followed in selection of props and gadgets used in the film as "workpieces". In machine-shop work, genuine parts should be used, not a demonstration workpiece that never ends up being a recognizable tool or part. If necessary, a simple part was designed, but an actual part that could be machined to illustrate the teaching problem usually was found. A training film should never be just an "exercise" or demonstration. The trainee should be shown an actual job in process.

In several films produced for the Navy on instrument control in the flying of aircraft, there were problems to solve. In the

entertainment field of motion picture production, considerable liberties are taken in presenting simulated flying conditions, aircraft control while in flight, and actual cockpit conditions. Our training films were to be used by advanced groups, men who had gone through their primary training and were ready for advanced procedures. A film that did not measure up to real-life conditions would have been laughed off the screen. To the technical advisers the Navy assigned to commercial producers, we are gratefully indebted. These men gave valuable assistance. If an SNJ aircraft was to be flown, the close-ups in the cockpit were made in an SNJ even though it worked considerable hardship on the camera crew. When aerial shots had to be made with the aircraft in the studio, we were most particular with the resulting simulated effect. Smoke bombs, mineral oil, and spray guns created an authentic overcast.

Strict attention was given to all control movements in the cockpit. For example, every movement of the "stick" to control the movement of the aircraft was carefully rehearsed so that the amount of movement corresponded to that used in actual flight.

When flying in overcast weather, considerable moisture accumulates and runs down the front of the cockpit windshield. The mineral oil gave that same desired effect and created a misty windshield. Flying scenes were made in overcast weather, with both the camera plane and the subject plane flying in and out of the overcast. This was the type of weather trainees were expected to experience, so it was made as genuine as possible.

CAMERA ANGLES

In a recent Hollywood production, "Lady in the Lake", produced and directed by Robert Montgomery, training-film camera technique has been employed. The camera is used as the narrator, and the audience views the story through the eyes of the storyteller. One of the important things in making training films is to choose a camera angle which is called the "operator's viewpoint". The scene is shot from as near an angle as the operator views the controls, the workpiece, or the reading of a micrometer. In the usual factual film, the camera angle is selected for good photography, or perhaps an impressive low-angle shot. Not so with the training film. The trainee must see the picture as if through the eyes of the man operating the machine. The camera must have that viewpoint.

Very often this imposes a difficult assignment on the cameraman, not only in camera placement, but in lighting. But it pays off in good training-film technique for the trainee sees a control wheel actually turned left, not in the opposite direction as would be the case if it were photographed facing the operator of the machine.

In many training films, especially those on precision-measurement work, we found that the usual extreme close-up was not close enough. A new photographic word was coined to mean an ultra-extreme close-up, and that word was "macrophoto". The standard lenses on the Mitchell and Bell-Howell cameras used would not rack out far enough to give this close a close-up, so Howard Cress of our Camera Department, turned out some lens-extension tubes. Thus, close-ups of great magnification were obtained with unusual photographic effects. For example, to show a small "burr" on the side of an aluminum pump block, a macrophoto was made. The small "burr" was approximately one-half inch in width but in the close-up, this "burr" filled two thirds of the plate.

Many times these enormous close-ups were used when micrometer readings were to be taken. In such close-ups, we were able actually to show the readings on the barrel of the "mike". So with the training film, came a new word in motion picture language, the macrophoto.

Selection of a camera angle is most important when measuring or checking dimensions with a dial indicator. The usual method is to shoot the workpiece being measured, and then photograph an extreme close-up of a dial set to the correct dimension and intercut these two shots. Whenever possible the camera angle was arranged so that *both* the workpiece to be checked and measured and the dial indicator were in the shot. The trainee was sure that the measurements were being taken on the actual workpiece. This often called for a change of focus and some rather odd setups, because the dial indicator might be 10 or 11 inches from the plane of focus of the measuring device. Other times a short pan or tilt-up to the dial would suffice to convince the trainee that no camera tricks were employed. The method we used was far more acceptable to the technical men in the business.

SELECTION AND REHEARSAL OF TALENT

The usual cast for a factual and documentary film is composed of professional actors. This is not possible in training films which deal

with specialized fields and talents. Experts were employed in the specialized field the training film embraced, and schooled in motion picture acting.

There is, at the beginning of the shooting schedule, a slight delay in having to instruct the mechanic, electrician, foundryman, or draftsman in motion picture technique. But within a day or two at the most, shooting schedules are speeded up using the man who "knows his business". These technical men often worked with the writers when the process to be photographed was put into script form. Therefore, they knew the entire film story and there was a double check that the scene was all right after the director called "Cut".

In the usual training film, 75 per cent of the footage is close-up and the face of the character is not seen. The hands and what those hands do are most important. It is the manner in which a skilled mechanic's hand picks up tools, turns dials, and handles workpieces with a sureness and confidence that brings to training-film photography an art that a professional motion picture actor can never learn. That is logical because the machinist may have spent a lifetime doing just what is being photographed.

In using talent skilled in the field of the training-film subject, the possibility of retakes is also minimized. If careful judgment is used in the selection of camera angles and the technician approves the action of a take, there will be little argument when the "rushes" are screened. No expensive retakes will be necessary as sometimes happens *after* the rushes are screened.

To retake some scenes would have meant delays and added expense. One script called for an electrician to tear up a floor to pull in armored cable. This called for skill and know-how, without benefit of rehearsal. Another bit of action required the electrician to remove a section of wall paper, then cut through plaster and lath. Here, a wrong movement would have required redoing and patching up the wall, waiting for the plaster to dry out, an expensive delay. The electrician-actor employed was an old hand at these tricks, he did his work swiftly, accurately. Many of these scenes would not allow rehearsal of the complete action, only sketchily outlining the action for camera lines. These were really "one-shot" takes.

To achieve such results, co-ordination between the technician, the director, and the cameraman is required. It can and has been done when attention is given in selecting talent for training-film production.

EDITING TECHNIQUE

It must be remembered that the training film does not entertain, but shows why, how, when, and what for, and therefore editing tempo must be considered. Entertainment films are edited according to type; fast comedy, heavy drama, action pictures; all have a technique of editing for tempo.

In editing a training film, there should not be cuts that are confusing as to orientation of the trainee's viewpoint as he watches a machine process. Generally, scenes should run long; short three- or four-foot scenes are confusing, unless the same angle has been shown before for orientation.

Selecting one take, and running that take through a "cycle" is better than trying to get a variety of angles. In training films one good camera angle of a cycle is better than trying to edit the film so that several angles can be intercut.

The usual factual or documentary film uses narration on about 90 per cent of the footage, the other 10 per cent is music, effects, or runs silent. The properly produced and edited training film should have about 45 per cent of the footage with narration; 55 per cent of the footage silent, as we know that 76 per cent of all impressions are made through the eye. Off-stage voice is used to guide the thinking of the audience, or to point up a certain action for emphasis. Some training films have scenes running 120 to 150 feet in length with only forty or fifty words of narration. "Let the picture tell the story" is a good maxim for good training-film editing and scoring.

Slightly off the scheduled subtopics of this paper is this added thought: the type of scenario for shooting a training film. The most important part of that script is the "action continuity". There must be smooth, concise, and complete continuity of each sequence. The narration included with the "shooting script" can be tentative for it is usually revised several times before the picture is recorded. A script with complete "action continuity" is an aid to be sure that the picture tells the story.

For the many hundreds of training films to be made, perhaps these comments will help produce films that will do a better job training new technicians for our mechanized world.

LIGHT GENERATION BY THE HIGH-INTENSITY CARBON ARC*

F. T. BOWDITCH**

***Summary.**—The theory of light production in the high-intensity carbon arc is discussed, together with a description of the phenomena associated with the initial striking of the arc and the maintenance of the electric discharge through the arc stream. The formation of the positive carbon crater is described and the factors defined which determine the maximum current loading which a particular carbon electrode will support. The importance of efficient heat dissipation from the positive crater region in extending the useful current range of a given-sized carbon is pointed out, and the effectiveness of water cooling in providing better heat dissipation at this point is noted.*

In the motion picture industry, light is perhaps the most important single factor in the recording and reproducing processes involved. Light is thrown in carefully controlled quantities and distribution patterns on the motion picture sets and on the actors. Reflected portions of this incident energy are directed toward a camera lens, and focused to produce a permanent record of this reflected pattern on film. Finally, light is selectively absorbed by prints from this film in a theater, so that the distribution pattern reaching the original film in the studio camera may be recreated on the theater screen. Light is also an essential agent in the recording and reproduction of sound, although that important phase of the industry will not be included in this present consideration.

The high-intensity carbon arc is such a commonplace and generally useful light source in the photographic and projection processes which characterize the motion picture industry[1, 2] that little thought ordinarily is given to the physical processes involved in the operation of such a source. In the belief that concepts found useful in the laboratory in directing the development of new and brighter carbons may be of interest to the ultimate users of such carbons, the present discussion has been prepared.

To begin with, consider the simple arc circuit of Fig. 1. Here a direct-current source of perhaps 110 volts is connected through a series resistor to a pair of carbons. In common with all gaseous discharges, the carbon arc has a negative resistance coefficient: as the

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** Research Laboratories, National Carbon Company, Inc., Cleveland 1, Ohio.

current is increased, the ohmic resistance of the arc becomes less. Some ballast effect, such as is provided by the series resistor in this case, must, therefore, be incorporated in the circuit. To start the arc, the two carbon electrodes are brought into brief contact, drawn apart again, and a light source of very high intensity is produced where nothing but air existed before.

When the power is first applied, nothing happens, because the circuit includes an air gap between the carbon electrodes which cannot be broken down by the relatively low voltage of the power source. It is not until the electrodes are brought into physical contact that current starts to flow. In a series circuit, such as is established when the electrodes touch, the same current flows throughout, so that the

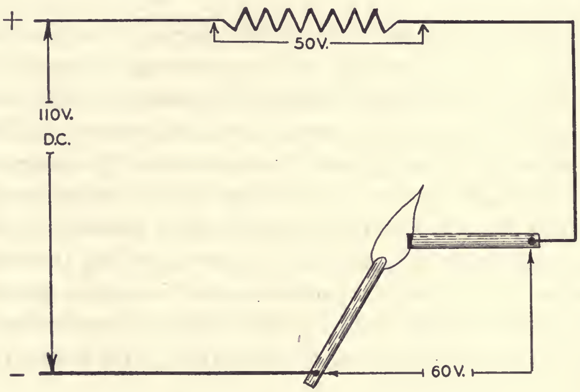

FIG. 1. A typical carbon-arc circuit.

relative heat in any portion of the circuit is determined by the resistance of that portion. At the point of contact between the electrodes, the cross-sectional area is small, so that the resistance is high. As a result, a high concentration of heat is produced at this point; and as the pressure on the electrodes is reduced, preparatory to separating them, the contact area grows smaller and smaller, so that it continues to become hotter and hotter.

In order to explain what happens next, it is necessary to consider an atomic property of hot bodies called thermionic emission. The atoms in any solid substance are in a continual state of vibration, with electrons revolving rapidly around each nucleus in a variety of orbits at various distances. When the substance is heated, the atomic vibrations grow more intense, and the electrons spin faster and faster through wider and wider orbits. In the case of those atoms next the

surface, an occasional electron will break away altogether, and as the heating continues more and more electrons fly off into space.

Hot carbon is not so good an emitter of electrons as the materials used for this purpose in vacuum tubes, but it does possess this property to an appreciable degree. Thus, to return to the arc, as the last pair of atoms is about to be drawn apart in the separation of the electrodes, the concentration of current and the intensity of the resultant heat are terrific, sufficient not only to cause thermionic emission, but to vaporize the carbon itself at the tiny area of final contact. Consider also what would happen at the instant of separation if no arc were to form, so that the current would fall abruptly to zero. The full open-circuit line voltage would immediately appear across the gap, and if the initial gap is assumed to be a millionth of an inch, and the line voltage 100 volts, a voltage gradient of 100,000,000 volts per inch would be established promptly. As a matter of fact, the distance between atoms in solid carbon is something of the order of 20 billionths of an inch, and it might be assumed that at the instant contact is broken, the physical separation is of this magnitude, which would give a voltage gradient of five billion volts per inch.

It naturally follows that such a tremendous voltage gradient, acting in combination with the free electrons around the white-hot electrode tips, causes enough of them to flow across the gap as the carbons are pulled apart so that current continues to flow through the hot gases, and an arc is established. In turn, the high concentration of power within the narrow confines of the arc produces light, after the following fashion:

To begin with, there is incandescent carbon at its volatilization temperature of over 6500 F (3600 C). Since a temperature of only 2600–2900 F (1425–1595 C) is enough to produce a "white heat", it is apparent that incandescent carbon alone is responsible for a good share of the brightness of the carbon-arc crater; for all of it, as a matter of fact, in the low-intensity carbon arc, and from a fifth to a half of the total brightness in common high-intensity trims.[3]

The increased brightness of the high-intensity arc is the result of the combination of a high current density, *i. e.*, a high concentration of electrons in the arc stream, and an atmosphere in the positive crater region rich in "flame materials" volatilized from the special coring of the positive electrode. These flame materials are in most cases compounds of the cerium group of rare-earth metals, combined in a mixture with carbon in the core. As the carbon shell burns away to form

a crater, as indicated by Fig. 2, the core is exposed to the extreme arc temperature and is vaporized into the crater enclosure. Here, the rare-earth particles are bombarded by electrons to produce very intense light. It is perhaps helpful here to picture a maelstrom in the positive crater, with many billions of rare-earth atoms continually colliding with as many electrons. As the result of each collision, a rare-earth atom absorbs energy from an electron, and is transformed into an "excited" state. In other words, the excited atom possesses

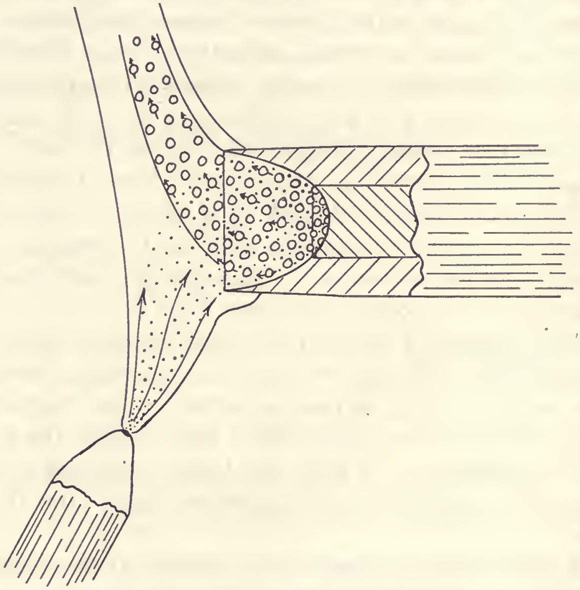

FIG. 2. Diagram showing the mixture of rare-earth atoms and electrons in the positive crater of the high-intensity carbon arc.

an amount of energy in excess of the normal stable value. Moreover, as defined by quantum theory, this excess energy may have any one of a number of discrete values, depending upon the number and arrangement of the electrons circulating around the atomic nucleus. The rare-earth atoms have many electrons (cerium has 58, circulating in 14 different orbits) so that the likelihood of scoring a hit on such a large, well-populated target is correspondingly increased. At the same time, there are a great many excited states possible, so that the likelihood is excellent that a hit will produce excitation. Since the rare-earth atoms are not stable in these excited states, they immediately

give up their excess energy. This they do in the form of pulses of radiation, each having a particular wavelength associated with the excited state; or an excited atom may return to a normal energy level in a series of discrete steps, emitting radiant-energy pulses of as many different wavelengths on the way. It is characteristic of the rare-earth atoms that these energy pulses are of wavelengths to which the human eye is sensitive, and that they are distributed in such great numbers over the range of visual sensitivity that an essentially equal energy spectrum or a "white" light is produced. In this way, the brightness of the high-intensity carbon-arc crater is increased many-fold over that of the plain carbon arc (to over ten times, in the laboratory).

Fig. 3, which shows a picture of a typical high-intensity carbon arc, can now be viewed with a new understanding of what is going on. From the incandescent tip of the negative carbon underneath, countless numbers of electrons are being drawn out into the arc stream and accelerated like bullets toward the positive electrode by the voltage gradient along the arc stream. To make enough electrons available, *i. e.*, 63, followed by 17 zeros, electrons per second for each ampere, the negative tip must be heated to a very high temperature, hence the bright tip and red heatback of this electrode. These electrons rush across the arc stream, meeting nothing much except air atoms until they approach the region of the positive carbon, a bluish light resulting from collisions with the air atoms in the arc stream. At the crater, and particularly inside it, the electron stream encounters the rare-earth atoms, with a resultant production of brilliant white light. Under the influence of convection currents established by the hot gases, a bright stream of excited rare-earth atoms emerges from the crater and drifts upward into the tail flame.

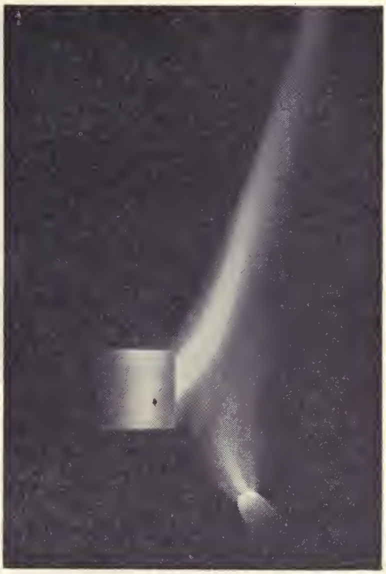

FIG. 3. The inclined trim high-intensity carbon arc. (13.6-mm positive carbon at 150 amperes with the negative directed upward at an angle of 53 degrees from the horizontal.)

Carbon is an ideal material from which to construct the electrodes for such an arc because of three important properties: (*a*) it is a good electrical conductor, (*b*) it remains in solid form to a very high temperature (approximately 6500 F (3600 C)), and (*c*) it volatilizes directly without passing through a messy molten state.[4]

The positive electrode of the high-intensity carbon arc differs from that employed with the low-intensity arc in two important respects. The core is not only much larger, but it is also heavily loaded with the flame materials whose light-producing function has just been described. In low-intensity positive carbons, the core hole is no more

FIG. 4. Comparison of the core sizes and craters of typical low- and high-intensity carbon arcs. (The deep high-intensity crater shown in the upper cross section was formed on a 13.6-mm carbon at 150 amperes, the almost flat low-intensity crater on a 12-mm carbon at 30 amperes.)

than one fourth the diameter of the shell: in the high-intensity positive carbon, the core is at least one half and is frequently a much greater proportion of the outside diameter of the shell. This is illustrated by Fig. 4. The current density is also much higher, a one-half inch low-intensity carbon operating at about 35 amperes as compared with well over 100 amperes for the same-sized high-intensity positive carbon.

Because of the lower voltage drop from the arc stream to the core as compared with the voltage drop to the carbon shell, most of the electrons forming the high current in the arc stream are encouraged to travel to the central core. Here the concentration of energy is so great that the core and the immediately surrounding shell are vaporized faster than the shell at the outside. Thus, as shown by Fig. 4, a

cup or crater is formed on the end of the positive carbon, which is filled with the rich light-producing mixture of rare-earth vapors and electrons. As the current is increased, the depth of this crater likewise increases to a limiting value determined by what is called the "overload" of the carbon. Overload is characterized by the fact that beyond a particular current value the arc no longer burns smoothly and quietly, but becomes unsteady and noisy. Since, for all important uses, the arc must be both stable and quiet, operation is always confined to currents well below this overload value.

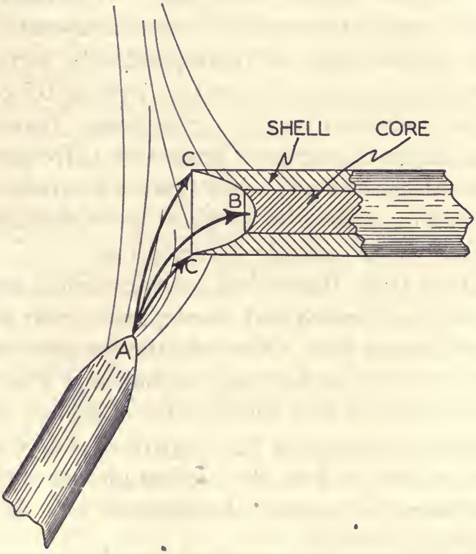

FIG. 5. Diagram illustrating the mechanism of overload in a high-intensity carbon arc.
AB = normal electron path to core
AC = overload electron path to carbon shell.

As shown in Fig. 5, the mechanism of overload is visualized as follows. Since the electrons encounter a much lower voltage drop in entering the positive carbon through the central core, the resulting crater becomes deeper and deeper with increasing current. At the same time, the tendency for electrons to flow directly to the shell C at the mouth of the crater, instead of taking the longer path to the bottom B, becomes greater and greater. Finally, the difference between the voltage drop over the longer arc stream AB to the bottom of the crater, and the voltage drop along the shorter path AC to the crater

lip, becomes sufficient to counteract the effect of the more favorable electron entrance into the core. When this happens, the electrons travel in increasing numbers to the shell. Here the rate of energy release increases to a point where carbon is volatilized violently and noisily. Thus, an upper limit of about 35 volts (the anode drop to pure carbon) seems to be imposed on the voltage component of the energy which can be released within the positive crater. The current component of this energy is less rigidly limited. For instance, water-cooled positive jaws may be employed, with a minimum protrusion of the positive carbon beyond these jaws.[5] The more efficient heat dissipation thus obtained permits the use of substantially higher currents and the achievement of correspondingly higher brilliancies. The added complication of arc operation with water-cooled jaws has so far prohibited their use in many applications. However, in motion picture studios where background projection is frequently employed to provide the setting for a physically distant location, operation with water-cooled jaws to achieve the brightest possible background image is receiving active experimental consideration.

It is hoped that these theoretical considerations, assembled in the course of arc-carbon research and development, have proved of interest outside that limited field. Not only the designers and the operators of the many types of burning mechanisms which facilitate the generation and release of this benign form of atomic energy, but also the many artisans engaged in the control of this energy to create wanted effects on film and on the motion picture screen, are all dependent upon the radiant output of the carbon arc. It is to them that this paper has been directed.

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DISCUSSION

MR. DOFFER: The speaker mentioned that carbon is a very good electrical conductor, therefore you had a low loss. Why do some carbons have a copper coating on them?

MR. F. T. BOWDITCH: Carbon is not so good an electrical conductor as copper. I didn't mean to imply that. But as compared with other materials which remain solid at a comparable temperature, carbon is an excellent conductor. A copper coating is applied to carbons in services where the current must be carried throughout the length of the carbon from fixed clamps at the end farthest from the arc. Bare carbons are ordinarily employed with current jaws which grip the carbons close to the arc, and through which the carbon is pushed forward by a feeding mechanism at the rear.

MR. READ: Does the alternation of the electron path from points A–B to points A–C take place about once a second or does it occur at a rate which produces an audible note?

MR. BOWDITCH: I did not mean to imply there was any alternation whatever.

MR. READ: I don't mean alternating current.

MR. BOWDITCH: The picture we have, and the picture I intended to portray, is that at reasonable currents, well below the overload limit, practically all the electrons take the longer path to the base of the crater. This is so because it only requires an anode drop of perhaps five volts to transfer electrons from the arc stream into the core at this point, as compared with 35 volts directly to carbon at the crater lip. Now as the crater becomes deeper, more and more electrons consistently take the shorter path to the crater lip (not first this way and then that way), until a sufficient electron concentration is developed to generate a very intense heat at that point. Every electron entering the carbon releases 35 electron-volts of energy as it lands there, and so is responsible for a very high concentration of energy.

MR. O. E. MILLER: Do you have positive-ion current in appreciable amount?

MR. BOWDITCH: Our measurements indicate that the positive ions carry only a small percentage of the total current. There is such an effect. However the energy relationships indicated by the crater radiation spectrum show that only a very small percentage of the rare-earth atoms are ionized. Positive-ion current, while present, is therefore considered to be a minor factor in the light-producing relationships involved.

MOTION PICTURE SCREEN LIGHT AS A FUNCTION OF CARBON-ARC-CRATER BRIGHTNESS DISTRIBUTION*

M. T. JONES**

Summary.—*This paper describes a theoretical method for determining motion picture screen light in a carbon-arc projection system, employing light measurements made directly on the arc crater from various angles of view. The opportunity is thus afforded to study the performance of a given carbon-arc source in optical systems having a much wider variety of collecting angle, magnification ratio, and optical speed than could possibly be assembled for actual optical-bench tests. In this way, it is hoped that the selection of the best possible optical system for a given arc will be facilitated, and vice versa.*

Examples of the application of the method to the 8-mm "Suprex" carbon arc at 70 amperes, and to the new 13.6-mm super-high-intensity carbon arc at 290 amperes are given. In each case the analysis has been extended for illustrative purposes over a wider range of optical systems than is of present practical interest. However, the general conclusions thus made possible were considered of sufficient theoretical interest to justify this otherwise impractical consideration. For instance, it is indicated that, particularly with the larger crater, the greater lumen pickup of a high collecting angle does not always result in more light on the screen.

Such practical checks of the method as have been made to date, comparing screen light measurements in complete optical systems with the values predicted by the method, indicate a useful order of accuracy for optical-design purposes. However, the limited scope of these checks is recognized, as is the fact that the calculations do not take screen color variations with focal position into account.

It is hoped that this paper will stimulate others to carry on this same type of analysis, and that the foundation will thus be laid for the most effective combination of carbon arcs with the associated optical systems.

In practically every 35-mm motion picture projection system, the light on the screen originates in the crater of a carbon arc. It is collected by a mirror or condenser and focused on a picture held in the film gate; the picture thus illuminated is imaged on the screen by the projection lens. An important part of the study of a carbon arc for this service is the evaluation of the light output from the arc crater in terms of the screen illumination produced after the light passes through such a chain of optical elements. The method of evaluation described herein is based upon measurements of the brightness distribution over the arc-crater region from various angles of view, and the mathematical integration of these measurements to yield aperture

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** National Carbon Company, Inc., Fostoria, Ohio.

illumination data. In this way, the performance of a particular carbon arc in a wide variety of systems of different optical speed, magnification ratio, and pickup angle can be predicted. This reduces the time required for such an analysis to a small fraction of that required to cover this same range by actual assembly and over-all measurement of the many individual systems. Such a procedure thus contributes importantly to the determination of the best possible combination of carbon arc and optics to satisfy a particular projection requirement. In the present analysis, ellipsoidal mirrors are the only light-collecting elements directly treated, although it is shown that the procedure so developed can be applied with reasonable accuracy to condenser optics as well.

The characteristics of the optical system are such that each point on the screen receives light from many points in the arc. The resultant illumination is thus a complex function of the brightness distribution over the arc region. It is possible to measure this brightness distribution with considerable accuracy.[1] The next step in a calculation of screen light is therefore an analysis of such brightness data in combination with the optical properties of an ellipsoidal mirror. Both the manner in which light is collected from various angles of view of the crater region and the patterns in which this light is focused on the film gate must be considered to give the amount and distribution of the illumination there. Finally the action of the aperture, projection lens, shutters, heat filters, and draft glass in reducing the luminous flux and in changing its distribution must be considered to determine the light on the screen.

The light distribution projected on the film gate by an ellipsoidal mirror is calculated by a method similar to that developed by Benford for the distribution of light in a searchlight beam projected by a paraboloidal mirror.[2,3] However, in order that the process might find more extensive experimental use, it was necessary to develop many simplifications which permit rapid evaluation of a given arc without significant loss in accuracy. The procedure so developed is based upon the annular symmetry of the optical system. That is, all points in the mirror which lie on a circle centered on the axis, form crater images on the film gate which, for all practical purposes, are of the same size, shape, and brightness distribution. It is thus advantageous to treat each element of the system (the crater region, the mirror, and the film gate) in a series of concentric annular regions. The light contribution of each such region can be determined with

comparative ease, for summation with others similarly obtained. The method, then, is developed along the following lines:

(1) The film gate area is divided into a series of concentric zones of equal width, centered with the film aperture.

(2) The mirror surface is divided into a series of concentric segments of such width that all contribute alike to the illumination per unit area on the film gate. These segments must decrease in area with increasing angle of view, to compensate for the accompanying decrease in image-magnification ratio.

(3) Crater-brightness-distribution data are recorded from the angles of view corresponding to the effective centers of these mirror segments.

(4) Each projected crater area so explored is divided into a series of concentric zones of such width that, in combination with the average magnification ratio of the associated mirror segment, the crater-zone images at the film gate will exactly match the zones established there.

(5) The contribution of each mirror segment to the illumination of a particular zone on the film gate is determined from the crater-brightness values recorded over the associated zone at the crater. A summation with similar contributions of the other mirror segments gives the total illumination of that film-gate zone, and the similar treatment of each film-gate zone in turn gives the total illumination of the film gate.

(6) Finally, a determination of the film-gate illumination which enters the film aperture and the effect of the projection lens on it give a measure of incident screen light.

In brief, this is the method. A more detailed description requires a consideration of the fundamental properties of the ellipsoidal mirror.

THE ELLIPSOIDAL MIRROR

The surface of an ellipsoidal mirror is generated by the rotation of an ellipse about its major axis, A-A' of Fig. 1. Such a reflector possesses two symmetrical focuses, F_1 and F_2, so related that light emitted in any direction from either one is reflected to the other. Accordingly, as used in service, the arc crater is located facing the mirror at one focus F_1 and the film gate is placed at the other. The entire ellipsoid, shown at the top of Fig. 1, is never employed in such a motion picture projection system; only the section from P to P', shown separately below, is needed to fill the projection lens.

Since the carbon-arc crater must have a small but finite area in

order that its image on the film gate will be large enough to cover the aperture, light will originate not only from the true focus F_1, but from near-by off-axis points as well. When the paths of these off-axis rays are calculated from the geometry of the ellipse, it is found that each elemental area of the mirror focuses an image of the crater centrally upon the aperture. These images vary in shape and in size, depending upon the angle from which each elemental mirror area looks at the

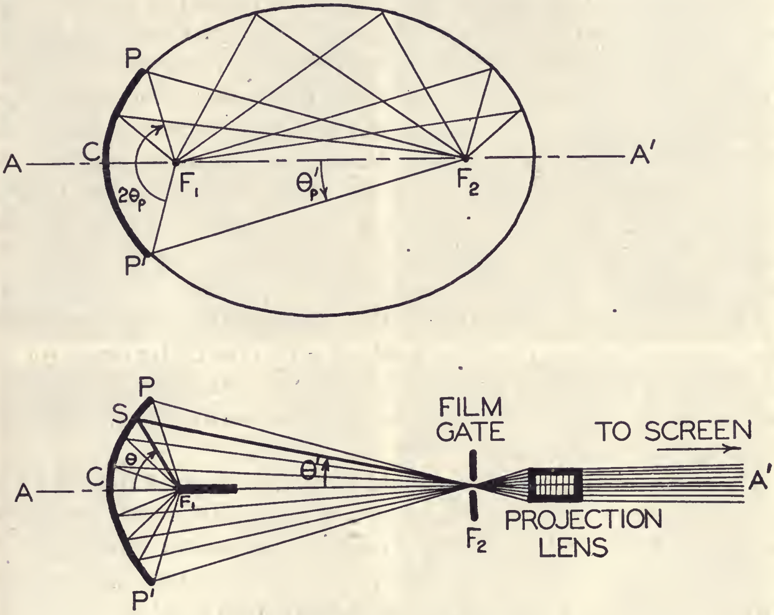

FIG. 1. Focusing action of ellipsoidal mirror.

crater. Referring to the lower drawing of Fig. 1, the size and shape of each image is related with this viewing angle θ (at the left) in the following way. As θ increases, the size of the image decreases. This is so since the magnification for any point S on the mirror is equal to the distance F_2S, divided by the distance F_1S; and it is apparent that the distance from mirror to film gate F_2S decreases as θ becomes larger. Also, the circular crater of the carbon arc appears to be an ellipse as viewed from any off-axis point S, so that an elliptical image is formed at F_2. The dimensions of this ellipse are

$$\text{major axis} - (F_2S/F_1S) \times (\text{crater diameter})$$

$$\text{minor axis} - \frac{(F_2S\cos\theta)}{(F_1S\cos\theta')} \times (\text{crater diameter}).$$

For simplification of later calculations, $\cos\theta'$ is assumed to be unity, since the angle θ' is always sufficiently small that no serious error is introduced in the results. (At $f/2.0$, $\cos\theta' = 0.97$; at $f/1.4$, $\cos\theta' = 0.94$.)

The variation in image with viewing angle θ is illustrated in Fig. 2, which shows arc images as they would be formed on a film gate for four different values of θ. The arc is the 13.6-mm National High Intensity Projector Positive operated at 150 amperes. For comparison, the outline of the standard 35-mm sound projection aperture has been superimposed, with its size adjusted to the axial magnification of 3, characteristic of the $f/2.2$ condenser system frequently employed with this arc. While this system has a maximum value of θ = approximately 40 degrees, the images out to θ = 75 degrees are shown to illustrate the degree of coverage obtained at the wider angles commonly employed with mirror systems. This is done for illustrative purposes only, since it is not practicable to employ an arc of this power with present-day mirror systems and since such a system would be much faster ($f/1.0$) than can be utilized in practice. While the forward crater image is much larger than the aperture (thus providing what appears to be an excessive waste of light), the crater image for an angle of θ = 75 degrees covers only a small portion of the aperture, because of the reduced magnification and the narrowness of the foreshortened view at this angle.

The image of the arc which would be formed by a complete mirror is a composite of many individual images, samples of which are shown in Fig. 2. The calculation of light passing the aperture must consider all these images. Moreover, light passing the aperture from images with large values of θ includes some light from in front of the crater, some from the crater itself, and some from the carbon shell behind the crater.

As long as the center of the crater is maintained at one focus of the mirror, the centers of all images will coincide with the center of the aperture, as shown in Fig. 1. This is the condition at which maximum light is projected on the screen. Accordingly, the present treatment has been confined to a consideration of the "in-focus" condition although it is possible to apply a similar treatment to "off-focus" conditions.

There are three fundamental constants which define the optical action of a given mirror. Using the designations of Fig. 1, these are

(1) the angle of collection—$2\theta_p$
(2) the speed (f number)—$1/2\tan\theta_p'$
(3) the nominal or axial magnification (M_0)—CF_2/CF_1.

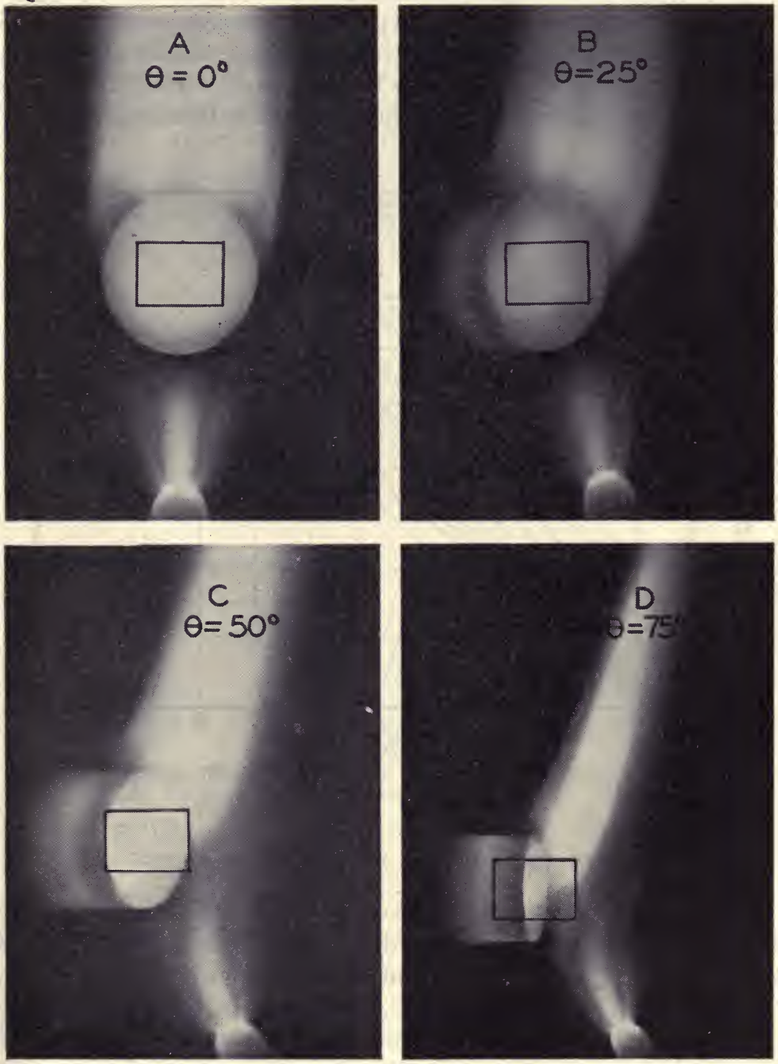

FIG. 2. 13.6-mm crater images projected upon aperture by zones of ellipsoidal mirror at angles of view to the side of the arc. 0.600 × 0.825-in. aperture. $M_o = 3$.

The fixing of any two of these quantities defines the third, the relations between them being plotted in Fig. 3.

With this background, then, it is possible to proceed with the selection of the film gate, mirror, and crater zones previously mentioned. The first and last of these will now be considered, leaving the mirror zones for separate consideration in an Appendix to this paper.

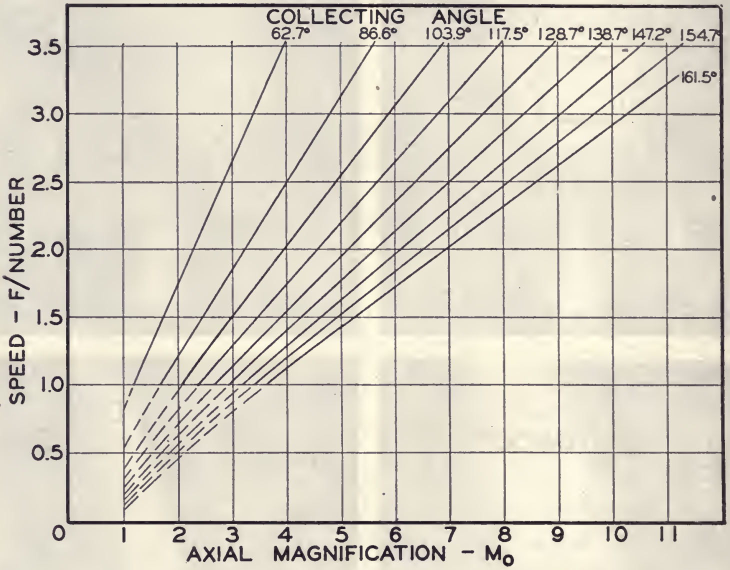

FIG. 3. Relations between speed, axial magnification, and collecting angle of ellipsoidal mirror.

SELECTION OF ZONES ON THE FILM GATE AND ON THE CRATER

The manner of selection of annular zones of equal width on the film gate and on the crater is illustrated in Fig. 4. For illustration, this figure has been drawn for an axial magnification of 3, corresponding to the arc photographs in Fig. 2. The rings on the film gate have been drawn with a width of 3.0 mm requiring a width of 1.0 mm for the matching rings on the crater when viewed from $\theta = 0$ degrees. As the angle of view increases to 25 degrees and to 75 degrees, the rings become wider, in direct compensation for the reduced magnification ratios at these angles. The portions of the crater region effective on a particular zone at the film gate thus vary widely with the angle of

view from the mirror. For instance, each drawing of Fig. 4 has an equal number of zones, although the crater areas so covered are widely different.

MAGNIFICATION RATIO

It is apparent that the crater-zone widths just described were fixed by the assumption of a 3-to-1 magnification ratio, and that the consideration of systems of different magnification would require the calculation of an entirely different set of zone widths. Accordingly, in order to facilitate the treatment of a variety of optical systems of

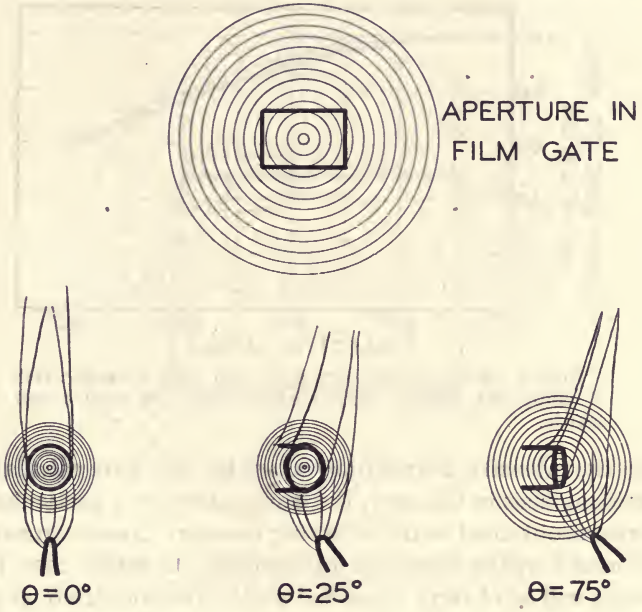

FIG. 4. Annular zones on crater corresponding to similar zones on film gate.

different magnification, it is advantageous to conduct the calculations on a proportional basis, introducing the magnifications of interest as a final step. To accomplish this, a hypothetical mirror of unit axial magnification is assumed, such that the proportional relation between magnification and viewing angle is the same as that of the average ellipsoidal mirror employed for motion picture projection. Fig. 5 shows that the characteristics of a mirror of $f/2.0$ speed accurately represent the average mirror in this respect. Such a mirror is approximately the average of mirrors with speeds from $f/1.3$ to $f/3.5$, the

range of greatest practical interest. Even with a speed of $f/1.0$, the error introduced by the assumption of the $f/2.0$ characteristics amounts to no more than 5 per cent.

For use with this proportional magnification system, a zone width of 0.5 mm on the film gate has been found to give results of satisfactory accuracy. The crater-zone widths from the axial viewpoint of $\theta = 0$ degrees then have this same dimension, and those at larger angles become progressively wider, in direct compensation for the reduction in magnification with angle.

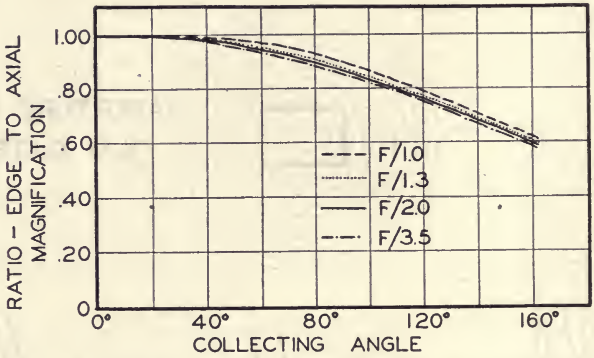

FIG. 5. Relation between axial and edge magnification of ellipsoidal mirrors with various collecting angles and speeds.

From the intensity distribution across the film gate calculated on a proportional basis in this way, the distribution for a particular mirror of interest is obtained in the following manner. Again, an axial magnification of 3 will be chosen as an example. In such a case, the film-gate zones will be of three times the width first calculated, or 1.5 mm. Therefore, the light will be distributed over nine times the area so that the intensities first calculated must be divided by that factor.

APERTURE TRANSMISSION

The procedure so far described gives only the zonal illumination on the film gate. However, only the light which passes through the film aperture is of interest. Therefore, as shown in Fig. 6, it is necessary to determine that portion of the zonal illumination which is included within the rectangle. While this might be done by a rather tedious graphical procedure, apparent from an examination of Fig. 6, a much faster method is preferred. Such a method is described in the Appendix to this paper.

A TYPICAL CARBON-ARC ANALYSIS

In addition to describing the procedure for calculating mirror-zone widths and a short-cut method for determining that portion of the film-gate illumination which passes through the aperture, the Appendix carries through a typical calculation from actual arc measurements. The utility of the information so derived will now be discussed.

Fig. 7 shows such data for the new 13.6-mm super-high-intensity positive carbon at 290 amperes.[4] The following conclusions are typical of those possible from such data:

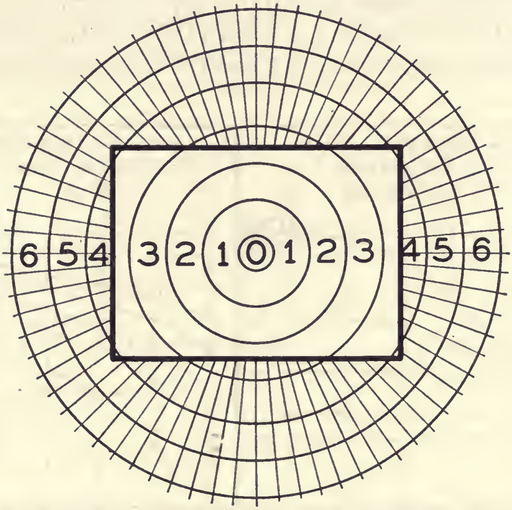

FIG. 6. Superposition of annular zones upon 0.600-× 0.825-in. aperture when $M_o = 5.4$.

(1) At a given speed, the side-to-center distribution ratio increases with collecting angle.

(2) At a given collecting angle, the side-to-center distribution ratio decreases with increasing speed.

(3) The luminous flux passed by the aperture does not increase in proportion to the light collected from the crater. With an $f/2.5$ system, for instance, this flux varies no more than ±7 per cent from an average value of 45,000 lumens as the collecting angle is varied from 60 to 140 degrees. With faster speeds, a more pronounced change in aperture flux occurs with change in collecting angle, with a peak value in all cases at some angle less than 140 degrees.

(4) The side-to-center distribution ratio at a given optical speed increases consistently with increasing collecting angle. However, with a constant lumen system, such as the $f/2.5$, the distribution ratio can only be increased by shifting light from the center toward the edges of the aperture. The higher ratios are thus achieved at the expense of a lower central-light intensity.

(5) If a given distribution ratio is desired, say 70 per cent, the luminous flux will be:

45,000 lumens at $f/2.5$ and 62° collecting angle
70,000 lumens at $f/2.0$ and 86° collecting angle
100,000 lumens at $f/1.6$ and 112° collecting angle
138,000 lumens at $f/1.3$ and 138° collecting angle.

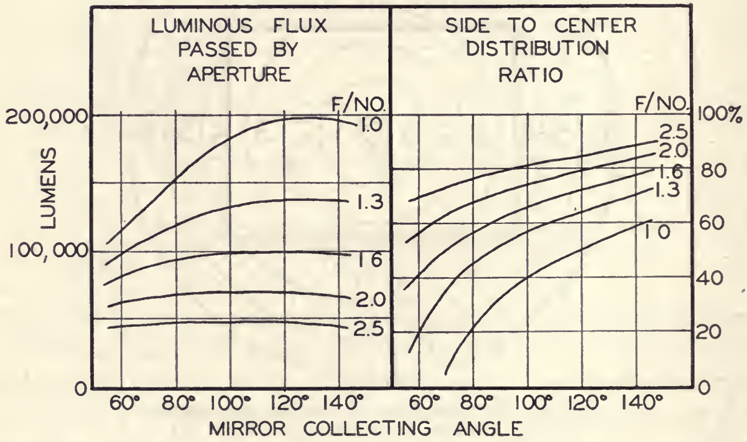

FIG. 7. Analysis of light passed by aperture with various ellipsoidal mirrors and the new 13.6-mm super-high-intensity positive carbon at 290 amperes.

At $f/1.0$, a distribution ratio no greater than 60 per cent can be obtained within the range of collecting angles investigated. Thus, as the speed is increased, the collecting angle required to produce a given distribution ratio and the luminous flux increases. A larger crater size would be necessary to obtain a 70 per cent distribution ratio at $f/1.0$. Also, where speed is limited, to $f/2.0$ say, the data do not justify the use of a collecting angle higher than 90 degrees with this particular arc. It is also indicated that carbons smaller than 13.6 mm can be used with adequate aperture coverage.

The 13.6-mm carbon just analyzed is not intended for use in mirror systems, but demonstrates the type of information available from the calculations described herein. The calculated performance of the 8-mm–7-mm "National" Suprex arc at 70 amperes shown in Fig. 8 provides an example of an arc intended for use with mirror systems. The curves are similar to those for the 13.6-mm carbon just discussed and similar conclusions may be drawn with the following comments.

(1) The side-to-center distribution-ratio curves at a given speed now flatten with increasing collecting angle.

(2) Because of the smaller crater size the side-to-center distribution ratio at a given speed is much lower than for the 13.6-mm carbon. The $f/1.0$ and $f/1.3$ speeds are not shown in Fig. 8 because the aperture coverage is far from adequate with these.

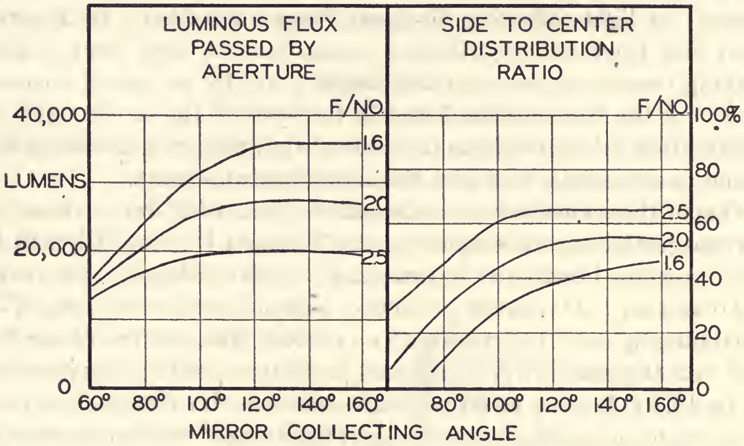

FIG. 8. Analysis of light passed by aperture with various ellipsoidal mirrors and the 8-mm–7-mm "National" Suprex trim at 70 amperes.

(3) Maximum luminous flux is reached at a collecting angle near 130 degrees with no advantage indicated for employing collecting angles higher than this with $f/2.5$ and $f/2.0$ speeds.

(4) The use of a lower collecting angle at these speeds would result in loss of light as well as in a lower distribution ratio with this carbon in contrast to the desirability for a lower collecting angle indicated for the 13.6-mm carbon previously described.

The usefulness of the method for calculating the luminous flux which a given carbon will pass through an aperture under various

optical conditions is thus effectively demonstrated. As a tool for evaluating the performance of a carbon arc, this procedure should prove extremely valuable.

RELATIONS BETWEEN LIGHT ON THE SCREEN AND THE LUMINOUS FLUX CALCULATED TO PASS THE APERTURE

In all the preceding considerations, no transmission losses in the optical system except those which occur at the aperture have been included. In order to translate the above-calculated luminous flux into light on the screen, it is necessary to take into account transmission losses such as mirror reflectivity, shadowing by the arc mechanism, heat filter, and draft glass, if employed, shutter, and projection lens. A treatment of this phase of the problem is beyond the scope of this paper. However, as a check on the validity of the calculations, several complete projection systems, both with mirrors and with condensers as light-collecting elements, were assembled. Both screen light and brightness-distribution measurements were made. After making reasonable assumptions, based partially on actual measurement, for the transmission losses in the system, the screen light and distribution calculated from the crater-brightness measurements were found to agree quite well with the actual measurements.

One of these checks was made with a standard 35-mm motion picture projection system employing the National 13.6-mm High-Intensity Projector Positive at 150 amperes. With condensers operated at $f/2.0$ and an $f/2.0$ coated projection lens of 5-inch focal length, the maximum light on the screen with no shutter, film, or filters of any kind and with the standard 35-mm sound projector aperture, was measured to be 19,500 lumens at 60 per cent side-to-center distribution ratio. The results of calculating screen light from crater-brightness measurements are given in Table 1.

TABLE 1

Screen Light Calculated from Brightness Measurements on Crater of 13.6-Mm High-Intensity Projector Positive at 150 Amperes

	Lumens	Side-to-Center Distribution Ratio, Per Cent
Luminous flux passed by aperture with no correction for transmission losses	38,000	73
Same including 69 per cent condenser transmission	26,200	73
Screen light after applying losses in projection lens	19,900	62

These condensers operate with approximately an 80-degree collecting angle; their measured transmission was 69 per cent. The transmission of the projection lens was measured to be 76 per cent with an 85 per cent side-to-center screen-distribution ratio from a uniformly illuminated aperture. The agreement between calculated and measured screen light values is within 2 per cent in this case.

The fact that a check with a value based on mirror theory was obtained when condensers were used indicates the similarity at the smaller angles in the focusing action between these two types of light-collecting elements. Accordingly, application of the calculations to simple condenser systems should be of use in evaluating carbon arcs for this application.

ACKNOWLEDGMENT

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APPENDIX

CHOICE OF ZONES ON MIRROR

The mirror is divided into a series of concentric annular zones of such width that each is equally effective in contributing to the illumination on the film gate. This choice simplifies the summation of crater-brightness data at all angles of view, in order to produce the illumination on the film gate for the entire mirror.

The determination of such a division of the mirror requires an integration over the mirror surface after the following manner. Referring to Fig. 9, the intensity of illumination on a small area S on the mirror from a unit area spherical source of brightness B at F_1, is B/R^2 where R is the distance from F_1 to S. The total luminous flux per unit area of the light source over the annulus including S is equal to B/R^2 times the area of the annulus. Employing polar co-ordinates, the total flux ϕ_M over the annulus whose edges are defined by θ_m and θ_n may be expressed as

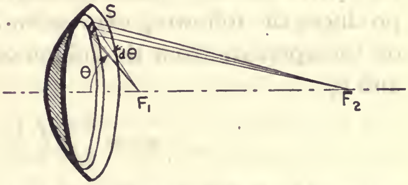

FIG. 9. Perspective view of annular zone on ellipsoidal mirror.

$$\phi_M = \int_{\theta_m}^{\theta_n} \frac{B}{R^2} (2\pi R^2 \sin \theta d\theta) \qquad (1)$$

where the integral of the term in parenthesis is the area of the annulus. This simplifies to

$$\phi_M = 2\pi B \int_{\theta_m}^{\theta_n} \sin \theta d\theta. \tag{2}$$

The total flux per unit area on the film gate ϕ_A reflected from this mirror zone is obtained by dividing ϕ_M by the square of the magnification, which is the ratio of the image area on the film gate to the area of the source. The total flux per unit area on the aperture is thus

$$\phi_A = 2\pi B \int_{\theta_m}^{\theta_n} \frac{\sin \theta}{M^2} d\theta \tag{3}$$

where M is the magnification at viewing angle θ. As previously discussed, the magnification M varies with θ. The relation between M and θ for any ellipse has been derived to be

$$M = k_1 + k_2 \cos \theta \tag{4}$$

where

$$k_1 = \frac{M_o + e}{1 + e} \tag{5}$$

and

$$k_2 = \frac{e(M_o + 1)}{1 + e}. \tag{6}$$

In these equations M_o is the nominal or axial magnification of the mirror, and e is the eccentricity of the ellipse employed to generate the mirror surface. Substitution of Eq (*4*) in Eq (*3*) and integration produces the following expression for the luminous flux per unit area on the aperture from the mirror zone bounded by viewing angles θ_m and θ_n:

$$\phi_A = \left[\frac{2\pi}{k_2}\left(\frac{1}{M_n} - \frac{1}{M_m}\right)\right] \times B \tag{7}$$

where M_m is the magnification at θ_m, and M_n that at θ_n. By substitution of Eq (*4*) this gives

$$\phi_A = \left[\frac{2\pi}{M_n M_m} (\cos \theta_m - \cos \theta_n)\right] \times B. \tag{8}$$

The expression in brackets in Eq (*8*) may be termed the "lumen factor" of a mirror zone, since it is the quantity by which crater brightness B must be multiplied to produce the luminous flux per unit area on the film gate. The "lumen factor" for the assumed "unit" magnification mirror is determined by multiplying Eq (*8*) by M_o^2.

The division of the mirror into annular zones of equal "lumen factor" produces the desired zones of equal effectiveness at the film gate. With such a choice of mirror zones, crater-brightness data effective for any one zone can be directly averaged with data for all other zones. The lumens per unit area on the aperture for the entire mirror may thus be found by averaging the effective brightnesses of all the zones and multiplying by the "lumen factor" for the entire mirror. The equal-lumen zones listed in Table 2 have been calculated for an $f/2.0$ mirror, although, as previously indicated, these are

TABLE 2

Zones of Equal Lumen Factor for an $f/2.0$ Ellipsoidal Mirror with $M_0 = 5.4$

Zone	Viewing Angle θ at Effective Center	Viewing Angle θ at Limits of Zone: Lower	Viewing Angle θ at Limits of Zone: Upper	Collecting Angle at Upper Limit	M/M_0 at Effective Center
1	22° 27′	0	31° 20′	62.7°	0.9635
2	37° 56′	31° 20′	43° 19′	86.6°	0.8979
3	47° 55′	43° 19′	51° 56′	103.9°	0.8407
4	55° 32′	51° 56′	58° 46′	117.5°	0.7904
5	61° 44′	58° 46′	64° 20′	128.7°	0.7457
6	66° 59′	64° 20′	69° 20′	138.7°	0.7058
7	71° 32′	69° 20′	73° 36′	147.2°	0.6700
8	75° 32′	73° 36′	77° 22′	154.7°	0.6376
9	79° 6′	77° 22′	80° 46′	161.5°	0.6082
10	82° 20′	80° 46′	83° 50′	167.7°	0.5814
11	85° 15′	83° 50′	86° 38′	173.3°	0.5569
12	87° 56′	86° 38′	89° 12′	178.4°	0.5343

"Lumen factor" for each zone is $0.9857/M_0^2$

equally useful with any mirror from $f/1.0$ to $f/3.5$ in speed. The number of zones indicated in Table 2 has been found sufficient to produce results of suitable accuracy for motion picture projection systems. The effective center of each zone is the viewing angle which divides the zone into two parts of equal lumen factor.

CALCULATION OF LIGHT PASSED BY APERTURE IN FILM GATE

In order to calculate the light passed by an aperture in the film gate, it is necessary to superimpose the aperture upon the illumination zones in the manner as shown in Fig. 6. This figure is drawn for an axial mirror magnification of $M_0 = 5.4$, which corresponds to an $f/2.0$ mirror of about 135-degree collection angle (see Fig. 3), and for the sound projection aperture 0.600×0.825 inch. Zones 0, 1, and 2 are entirely within the aperture. Zones 3, 4, and 5 are partially outside,

the percentage within the aperture decreasing with increasing zone number. All zones beyond zone 5 are completely outside the aperture.

The complications involved in determining the partial areas of circles superimposed upon a rectangle would add considerably to the difficulty of calculating light passed by the aperture for a large number of optical conditions of different magnification. To eliminate this, a short-cut method which takes into account the average distribution characteristics of carbon arcs has, therefore, been developed. As a first step, a circle of a diameter equal to nine tenths the aperture width is drawn, as shown in Fig. 10. In all cases with carbon arcs, the film

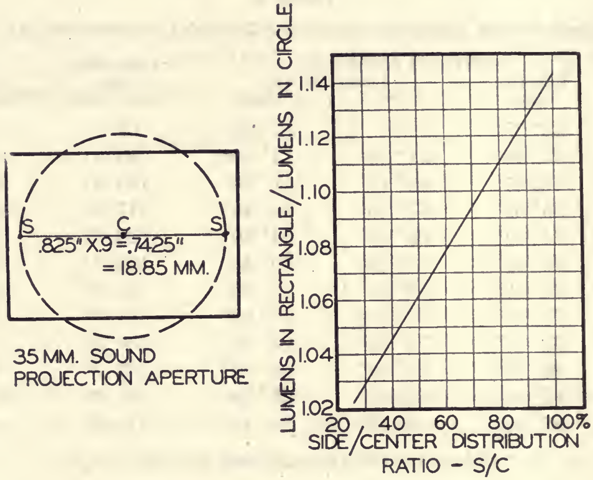

FIG. 10. Relation between luminous flux within 0.600- × 0.825-in. aperture and that within circle of diameter 0.9 times the long dimension of the aperture.

gate is illuminated most brightly at the center, and from this point the illumination decreases progressively in all radial directions. It is thus possible to prepare the chart shown at the right of Fig. 10, relating the lumens through the rectangle to those through the circle, for varying rates of illumination decrease away from the center. This chart is an empirical one, prepared from the calculation of many values of lumens through the aperture over the distribution range indicated. Values were obtained by the more precise method of determining the fractional parts of the circular zones shown in Fig. 6. In the simplified calculation, the determination of the lumens within the circle is a much easier task. A similar relation can be determined for apertures of other dimensions.

PROCEDURE FOR TAKING AND EVALUATING BRIGHTNESS DISTRIBUTION DATA

The method for taking and evaluating brightness-distribution data, including further assumptions made to simplify the procedure, is best described by carrying through an example. The new 13.6-mm Super High-Intensity Positive Carbon at 290 amperes has been chosen for this purpose.[4] Although this carbon is not intended for use with mirrors, it serves as an excellent example to demonstrate the type of information available from this method for calculating screen light. Fig. 11 shows brightness-distribution curves along the horizontal and vertical diameters of the crater area, as viewed from various angles in a horizontal plane, from one side of the carbon axis. Six of the mirror zones listed in Table 2 have been used, permitting calculation up to a collecting angle of 138.7 degrees. These brightness-distribution data show many of the features common to high-intensity carbon arcs of high brightness. Both the central and the maximum crater brightness decrease as the angle of view increases. The shape of the curves changes considerably with increasing angle of view. The effect of the foreshortening illustrated in Fig. 2D is apparent in the horizontal distribution curves, where a short vertical line has been drawn near the zero axis, at the left, to indicate the edge of the crater. At high values of θ, there is considerable brightness outside the crater (particularly in front) which is in a location contributing to light on the film gate.

It has been demonstrated that the amount of data given in Fig. 11 is adequate to yield results of reasonable accuracy, although a complete analysis of the crater would include views of the arc from both sides, as well as from areas of the mirror above and below the horizontal. Moreover, from each point of view, measurement of the brightness of all parts of the crater not included in the two diameters would be required. The following discussion justifies the simplification indicated by Fig. 11.

Only views from one side of the arc need to be considered because of two features common to the brightness distribution across the crater of almost all arcs. There is a vertical plane of symmetry passing through the centers of the crater, the tail-flame and the negative carbon. This allows the evaluation of all side views from one side of the arc only. In views of the crater varied in the vertical direction, there is considerably more luminous flux projected above and considerably less projected below the positive carbon axis than is projected along it, because of the presence of the tail-flame and of

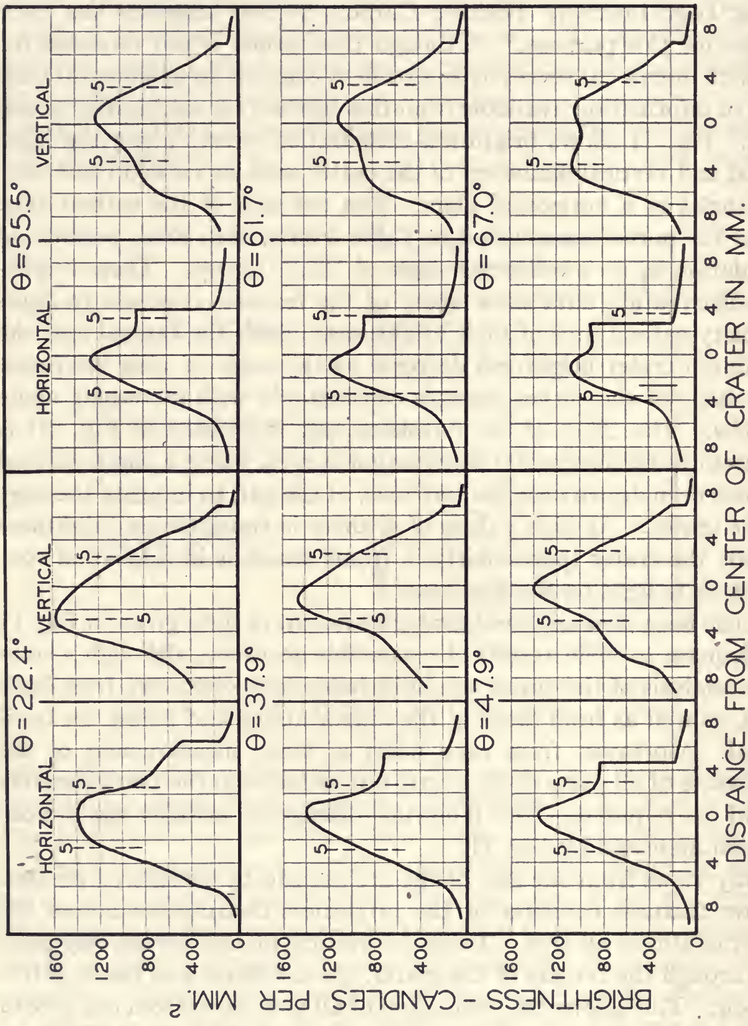

FIG. 11. Brightness distribution across crater of new 13.6-mm super-high-intensity positive carbon at 290 amperes, for angles of view suitable to calculate screen light.

the negative carbon. However, the average of the radiations at any given viewing angle above and below the axis is near enough to that at the corresponding angle in the horizontal plane so that the horizontal measurements alone are sufficient. As far as the mirror itself is concerned, limitation of the measurements to angles of view in a single plane to one side of the arc is justified because the mirror is a surface of revolution about the positive carbon axis. The dimensions of the crater image formed on the film gate are a function only of the viewing angle θ, irrespective of whether the view is up, down, or from the side. Thus, brightness-distribution measurements made at a viewing angle θ to the side can be assumed to apply to the complete annular zone of the mirror for which θ is constant.

Limitation of the brightness measurements to the horizontal and vertical diametral lines on the crater area has been justified by a comparison between crater candle-power values calculated from the horizontal and vertical data alone, and those calculated from a complete integration of the brightness over the entire area of the crater. Some cases have been found, particularly at large values of θ, where considerable disparity exists between candle power determined in these two ways. The brightness-distribution method can be made to agree with the precise integrating method by including brightness data from two 45-degree traverses of the crater.

The data in Fig. 11 are plotted with no dimensional change in the crater except that which results from the foreshortening. The variation in mirror magnification with angle of view is taken into account at the next step in the procedure. A set of transparent scales has been made, one for each equal-lumen mirror zone, for tabulating the brightness-distribution data at the radii which will be centered in the 0.5-mm image zones on the film gate. To make the distances on the crater as plotted in Fig. 11 correspond to the image distance at the gate, each scale is drawn with the spacing between divisions expanded as required by the zonal-magnification ratios listed in Table 2. The scales may then be laid over the corresponding brightness-distribution curves, and the brightness values at the intersections with the scale lines tabulated for the appropriate zones.

From each angle of view of the crater, four such brightness values are thus tabulated for each film-gate zone, two from the horizontal brightness-distribution curve, and two from the vertical. These are grouped with the corresponding values from other angles of view to obtain the average brightness of each film-gate zone. The averaging

at this stage introduces another assumption. The same symmetry which permitted the limitation of brightness measurements to angles of view in the horizontal plane to one side of the arc only, allows the brightness effective for any crater zone to be represented with sufficient accuracy by the average of four readings in the zone, two in the horizontal and two in the vertical diametral lines of the crater.

As an example, such a calculation will be carried through for film-gate zone 5. For unit magnification, the center of this zone is located 2.5 mm from the center of the film gate. The location of zone 5 as indicated by the transparent scales on each curve in Fig. 11 is shown by the vertical dashed lines. The brightness values so indicated are tabulated in Table 3, together with the average brightness for each mirror zone. The luminous flux from each mirror zone listed in Table 3 is obtained by multiplying the average brightness by the lumen factor (0.9857) and by the area of the film-gate zone (7.85 mm^2 for zone 5).

TABLE 3

Average Brightness and Luminous Flux on Film-Gate Zone 5 for New 13.6-Mm Super-High-Intensity Positive at 290 Amperes

Viewing Angle, Degrees	Brightness—C/Mm^2 on Diametral Line				Average Brightness for Mirror Zone	Lumens from Each Mirror Zone
	Horizontal		Vertical			
22.4	1144	992	1574	986	1174	9084
37.9	903	799	1178	948	957	7405
47.9	811	852	914	918	874	6763
55.5	774	862	876	842	838	6484
61.7	676	500	893	736	701	5424
67.0	635	166	1061	701	641	4940

The effective brightness and the total lumens projected on this zone by mirrors of collecting angles defined by each mirror zone in turn are listed in Table 4.

TABLE 4

Effective Brightness and Total Lumens on Film-Gate Zone 5 from New 13.6-Mm Super-High-Intensity Positive at 290 Amperes

Mirror-Collecting Angle, Degrees	Effective Brightness, C/Mm^2	Lumens on Zone 5
62.7	1174	9084
86.6	1066	16489
103.9	1002	23252
117.5	961	29736
128.7	909	35160
138.7	865	40100

Here, the effective brightness is the cumulative average of all the brightness values tabulated for mirror zones within the corresponding collection angle. Similarly, the lumens are the cumulative total of the lumens from each included zone.

To complete the picture at the film gate, this same procedure is carried through for each film-gate zone within the area of interest.

For greater usefulness, the luminous-flux and effective-brightness values may be plotted as shown for two collecting angles in Fig. 12.

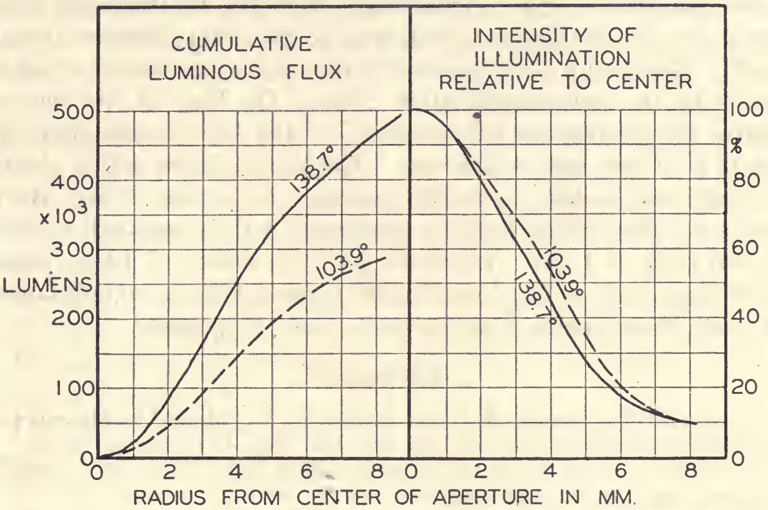

FIG. 12. Distribution of luminous flux on film gate when $M_o = 1$ for mirrors of collecting angles 103.9 and 138.7 degrees with new 13.6-mm super-high-intensity positive carbon at 290 amperes.

Here, in the upper pair of curves, the lumens are added cumulatively from the center of the film gate, so that the total lumens within any circle of interest can be conveniently determined. The ratio of intensity at the edge of the circle to that at the center can be read directly from the bottom curves. Here the ordinates were obtained by dividing the effective brightness of the outer film-gate zone by that at the center.

The luminous flux passed by an aperture in the film gate now may be calculated for any desired mirror, in the following manner. An $f/2.0$ mirror of 103.9-degree collecting angle will be taken as an example. Reference to the mirror characteristic curves of Fig. 3 shows

that such a mirror has an axial magnification of 3.95. Since the calculations have been based upon unit axial magnification to give zones of 0.5 mm width at the film gate, this mirror, with axial magnification 3.95, will collect and distribute the same luminous flux per crater zone into zones of width 3.95 times 0.5 mm at the film gate. To find the luminous flux within a given circle upon the film gate, the abscissas in Fig. 12 may be expanded by a factor of 3.95 to fulfill this condition.

The luminous flux through the 35-mm sound projection aperture is desired in this example. Accordingly, from Fig. 10, the radius of the circle for side distribution position is 18.85/2 mm (distance from C to S). Dividing by 3.95 yields 2.39 mm as the equivalent radius for use with the unit-magnification graph. On Fig. 12, the side-to-center distribution on the aperture for the 103.9-degree collecting angle is 76 per cent at 2.39 mm. The luminous flux within a circle of 2.39 mm radius is 64,000 lumens. As shown in Fig. 10, 76 per cent distribution ratio is associated with a rectangle-to-circle lumen ratio of 1.103. Therefore, an $f/2.0$ mirror of 103.9 degrees collecting angle will deliver 64,000 times 1.103, or 70,000 lumens through the aperture, with the carbon arc in question.

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ADAPTATIONS AND APPLICATIONS OF 16-MM MOTION PICTURE EQUIPMENT TO MEDICAL AND SCIENTIFIC NEEDS*

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Summary.—*Equipment designed to accomplish eardrum and other macrophotography is described as well as the construction and functional operation of equipment for photomicrography.*

INTRODUCTION

The Type of Work Done.—Our intention is to show how 16 mm motion picture equipment has been adapted for medical and scientific use. We should like first, however, to describe the type of work which is done so that you may more easily see how valuable and necessary these adaptations are. The work done is the planning and production of medical motion pictures and illustration—visual aids to learning—for the medical and scientific fields. It can be divided into three general classifications—undergraduate teaching, postgraduate or extension instruction, and the recording of visual observations.

In undergraduate teaching, subjects are prepared at class level and in suitable lengths for classroom periods. Films are made so as to be universally acceptable to all schools and to supplement the standard texts closely.

The majority of over 400 films on the approved list of the American College of Surgeons were designed for postgraduate and extension instruction. A physician graduating 5 or 10 years ago is 5 or 10 years behind in his profession unless he has been able to keep up to date by selected reading and regular visits to the teaching clinics. If he were able to read all the acceptable material printed and added to the medical libraries each year, he would have to read several volumes a day. If he did this, obviously he would have little time to practice his profession. Accordingly, motion picture digests of selected subjects dealing with new and approved techniques and treatments are prepared. These are approved by authoritative groups and made available to the practicing physician through State and County medical societies, hospital staffs, and allied groups.

The recording field covers many applications where visual records are desired for careful analysis and subsequent study, such

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as the recording of clinical findings for later study and comparison or the recording of observed phenomena for repetition at will.

The work is performed under the direction of such groups as the American Association of Medical Colleges, American Medical Association, and the American College of Surgeons. Photographic material is secured at individual medical schools, teaching hospitals and clinics, and research laboratories. The work is financed by established Foundations and by grants-in-aid from research groups and ethical pharmaceutical manufacturers.

The Need for Special Apparatus.—Much of the work, such as the photographic recording of clinical and surgical procedures, laboratory techniques, and similar items, can be adequately handled by the conventional 16-mm motion picture camera with a full complement of lenses up to 6 in. in focal length. Most lenses, however, will not focus at distances less than $1^1/_2$ or 2 ft. This leaves a vast no-man's land which can only be handled by special equipment or adaptations of existing equipment which will permit the making of macroscopic or microscopic motion pictures.

Paul Holinger has pioneered in the development of motion and still cameras for various types of endoscopic photography. His enthusiasm and unselfish assistance has made possible the development of similar equipment for macroscopic and other related purposes. Such a unit was described by La Rue, Sr., and Brubaker in the Sept., 1946, issue of the *Journal of the Biological Photographic Association.*

The Macroscopic Camera.—This unit, built around the Filmo Auto Load 16-mm cartridge camera, (Fig. 1), records minute areas and objects down to the point where they may be photographed under the low-power microscope. The mechanical arrangement of the unit provides for the support of light source, condenser lenses, water cell, 45-deg mirror, the Auto Load camera, and focusing telescope. A focusing knob with rack and pinion moves the whole ball-bearing-mounted assembly to focus on the area desired. An adjustable friction mechanism permits smooth operation and the locking of the camera at any desired focus.

The image *on the film* may be adjusted from one-half life-size to full life-size. At one to one, or actual size, it is possible to resolve clearly objects as small as 0.002 in. The very fine hairs found within the entrance to the ear canal can be seen well defined. The films of the eardrum, for which the instrument was primarily designed, clearly show the radiate fibrous layer of the drum membrane,

the radial lines being very prominent. There are, of course, many other applications for such a unit.

The light source is a 6-v 18-amp ribbon-filament lamp (Fig. 2). The 2-mm wide tungsten ribbon filament is focused by means of the condenser lenses upon the object plane. A 5-mm wide image of the filament is produced. The lamphouse is movable in relation to the

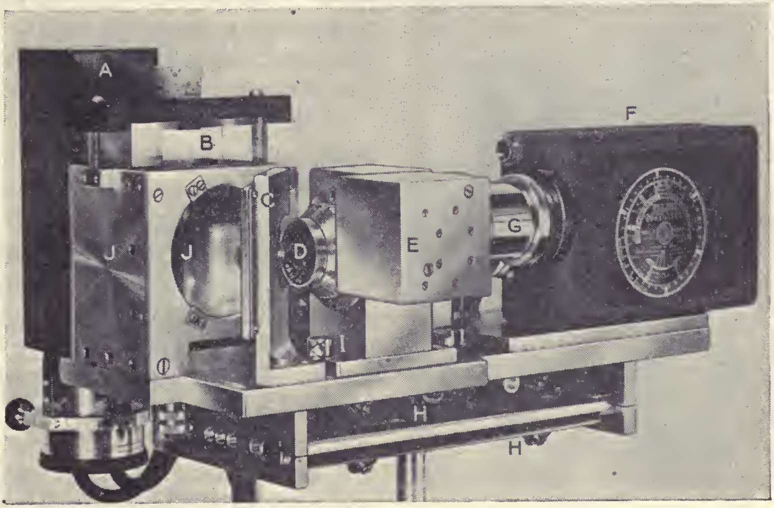

FIG. 1. General view, showing base, rods, bearings, and lens blocks.
A, Lamp base; *B*, Water cell; *C*, Mirror; *D*, Lens; *E*, Beam-splitter housing; *F*, Camera; *G*, Focusing telescope; *H-H*, Ball-bearing rollers on rod; *I-I*, Adjustment locks to control magnification factor; *J-J*, Condenser lens.

condenser lenses and thus provides for a range of adjustment of the image at the object plane. For surface macrocinematography, the filament image is projected in the same plane on which the camera is focused. At the lower-magnification ratios the image is thrown out of focus to illuminate a wider band of the object area.

A beam-splitter cube, immediately behind the camera lens, diverts a portion of the light to the erecting system and eyepiece of the focusing telescope. The remaining light forms the image on the photographic film.

The camera-release button is controlled by a solenoid. A beveled ring attached to a snap-action switch lever is located behind the focusing knob so that the camera can be focused, locked, started, and stopped with the right hand without removing the hand from

the knob. This control ring operates the switch and only a slight pressure of the thumb is required to operate it.

With constant supervision of focus by means of the telescope, instantaneous decisions can be made as to starting and stopping the camera or for corrections in focus while the camera is in operation.

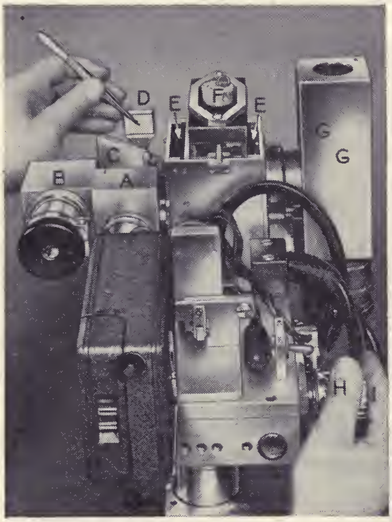

FIG. 2. Rear view showing focusing target (removable when working, only to be used to check focus and align lamp), focusing knob, microswitch, focusing telescope, and other parts.
A, Beam-splitter cube; *B*, Focusing telescope; *C*, Mirror; *D*, Focusing target (removable) for aligning lamp and checking focus; *E-E*, Condenser lens; *F*, Water cell; *G-G*, Light source; *H*, Release ring; *I*, Focusing knob.

Microcinematography in Color.—Much of the progress of medical science has been dependent upon microscopy. Many disease entities and most pathology can only be recognized under the microscope. Photomicrography (the photographing of specimens under the microscope) has been an important method of illustrating scientific papers and classroom lectures for a number of years. Most medical colleges have photographic departments equipped to make photomicrographs of selected specimens and fields as a matter of routine. The manufacturers of microscopes and microscopic equipment have manufactured equipment for this purpose.

With the advent of color, however, serious problems arose. All available color films were greatly reduced in speed and the maintenance of color temperature became an important factor. The making of black-and-white motion pictures through the microscope has always been a difficult procedure, but the making of color films at normal speed seemed almost impossible. Several microscope and camera manufacturers suggested several methods of accomplishing this, but none of the methods investigated completely answered the purpose. In order to meet the many requirements in microcinematography, it became necessary to develop an apparatus which would permit the making of motion pictures of objects under

the microscope *while being viewed by the operator.* An apparatus to permit this is pictured in Fig. 3.

In most cases it is necessary to go where the work is being done so that any equipment designed for this purpose had to be extremely light and portable. It was desirable to employ the standard type

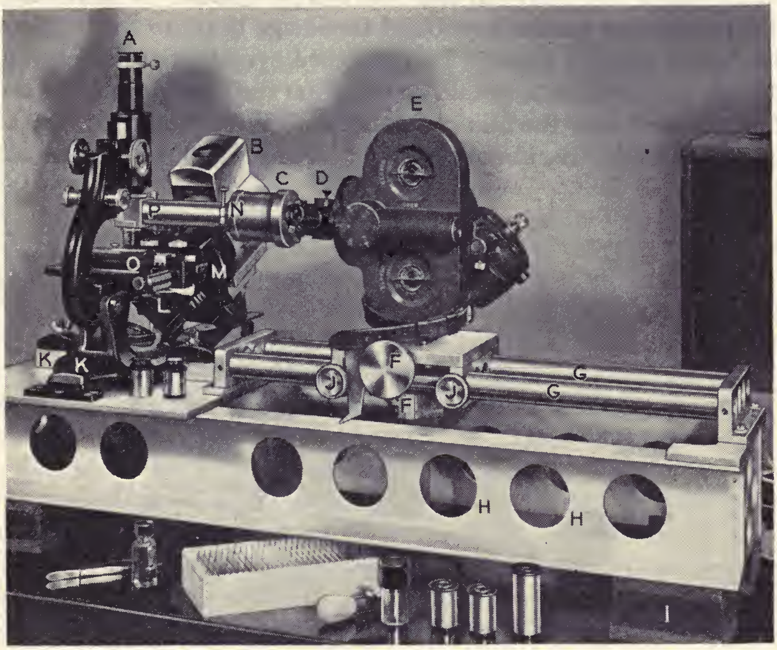

FIG. 3. General view of microscopic setup.

A, Compensating eyepiece; *B*, Lamphouse for ribbon filament lamp and No. 1 photoflood; *C*, Light trap; *D*, Reflex focuser; *E*, Camera (without lens); *F-F*, Adjustment for height; *G-G*, Hollow steel rods; *H-H*, Magnesium channels; *I*, Sponge-rubber pads; *J-J*, Lock position; *K-K*, Microscope held in jig; *L*, Filter holder; *M*, Water cell; *N*, Matched compensating eyepiece in light trap; *O*, Microstage; *P*, Beam-splitter cube; housing replaces the nosepiece of the microscope.

of microscope and attachments, and it was essential that the operator be able to view the field at the time the pictures were being made. For practical and economical reasons, the apparatus was designed to accommodate conventional 16-mm motion picture cameras. It is needless to say that the unit has to be sturdy and free of vibration and that the "setup" be simple and speedy. So that it might be operated in a normally illuminated room, it was necessary

to have a light-tight optical path from the microscope to camera. It was found that such an apparatus could be constructed with the optical system shown in Fig. 4.

Although this principle is well known, this particular application is the result of the efforts of J. D. Brubaker and W. B. Park. At the left is shown the conventional microscope optics. A split-beam cube reflects the greater portion of the image beam to the eyepiece just before the film plane. Two matched eyepieces are employed. Though it is possible to obtain an image on the film without the use of an eyepiece near the film plane, the employment of this eyepiece corrects for objective aberrations and further simplifies operation.

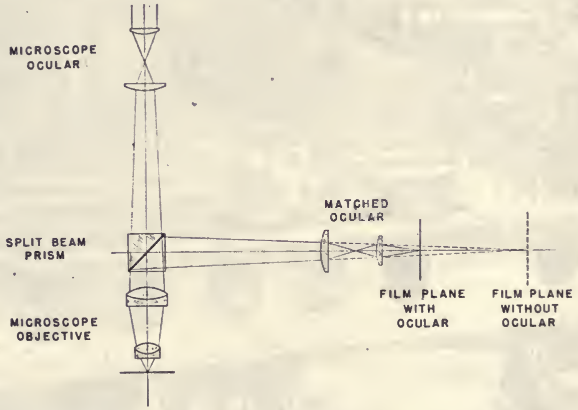

FIG. 4. Optical diagram.

In Fig. 3 is seen the result. The base is constructed of magnesium channels and the optical rods, or bench rods, are of hollow steel and mounted in adjustable blocks for initial alignment. The microscope hold-down blocks are of bakelite and a magnesium rod extends from the back with threaded holes to support the various types of light sources used. This rod is removable to simplify transportation from place to place. A conventional type of microscope is employed, the nosepiece being replaced with the split-beam housing. The microscope objectives and eyepieces are standard and the stage of the microscope is one of the better micro types. The camera support is adjustable in height to compensate for the various objectives used.

On location it is a simple matter to set up the apparatus in a convenient place for operation. This is usually on a table or desk in or adjacent to the clinic or laboratory. The microscope is fixed in its

jig and locked into position. The extension tube from the split-beam housing is screwed into position and the light trap attached. The camera is then mounted on its tripod screw and a Goerz reflex focusing device is screwed into position taking the place of the lens. On the end of the reflex focusing device the other part of the light trap is screwed into position. The light source is then mounted and centered in the usual manner. The compensating eyepieces are matched as to focus—the camera being moved along the rods to the extreme right position so as to permit inspection through the camera eyepiece.

When the whole apparatus is set up and adjusted, it is mounted on sponge-rubber pads to prevent vibration from being transmitted to the apparatus. While there is some vibration during the course of exposure, the whole apparatus vibrates as a unit and motion pictures have been made at speeds up to 64 frames per sec without any unsteadiness on the screen. The light source employed is a 6-v 18-amp ribbon-filament lamp for which a photoflood may be substituted when using a 25-mm or longer focal-length objective. The lamphouse is especially designed to accommodate both the photoflood and the ribbon-filament lamp together with the standard water cell and filter holders.

The use of the reflex focuser increases the magnification to some extent because of the lengthened optical path. Its use is desirable because it permits a constant check on the image reaching the aperture but is not used if magnifications must be exact. When the magnification must be exact with that viewed through the eyepiece, the reflex focuser is dispensed with and focusing is accomplished with a prism in the aperture of the camera.

All the possibilities surrounding the use of this equipment have not been explored. As an example, Nicholl and Webb of the University of Indiana have been engaged for the past several years in blood-circulation studies utilizing the wing of the bat. They have inspected and tested this equipment and as a result a similar apparatus, with a modification to permit the use of a dissecting microscope, has been designed. Their desire is to record their findings visually during their research so as to allow repetition and group study at leisure.

Animation.—In the production of medical teaching films, much of the information and material which cannot be pictured by conventional methods can be diagrammatically portrayed by means of animation on 16-mm color film. This also demands special equipment. The subject, however, is beyond the scope of the present paper.

KODACHROME MOTION PICTURES OF THE HUMAN AIR AND FOOD PASSAGES*

PAUL H. HOLINGER, M.D.,** AND J. D. BRUBAKER†

Summary.—*Special photographic equipment and techniques have been developed for motion picture photography of the human air and food passages. These films graphically visualize the vocal cords, windpipe and bronchial tubes, and the esophagus from the mouth to the stomach, to provide unusual clinical records that are invaluable as teaching and research material.*

The camera developed for this work permits constant visualization through the bronchoscope for finding and focusing as well as during the actual filming.

Advances in the field of photography have left few of the body cavities inaccessible to the camera. Such photography is an important method of recording the normal anatomy and diseased states of these areas. This paper concerns photography of the cavities visualized through the mouth, including the interior of the mouth and nose, the vocal cords, the windpipe, the bronchial tubes and the esophagus; these constitute the respiratory tract and the food passage from the mouth to the stomach. Films made of these areas depict the normal respiratory and swallowing functions, and assist in the study of the action of the vocal cords and the mechanism of speech production. As clinical records, the films permit careful study of tumors, inflammatory processes, and even the mechanics of diagnosis and manipulation for removal of bizarre objects such as pennies, safety pins, tacks, and similar items that find their way into the air and food passages of infants and children.

Before proceeding with a description of the camera, an analysis of the problems encountered should be described. The vocal cords may be photographed through a tube approximately $^5/_8$ to $^3/_4$ in. in diameter and 6 to 8 in. in length. The tube for photography of the bronchi and esophagus may have a maximum diameter of $^5/_8$ in., and must be at least 14 in. long. Only open tubes, rather than tubes containing lenses, may be used because it is necessary for the patient to continue breathing through the tube as the airway is being examined. Thus the problem consists in designing an apparatus for photography of the

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area seen through a $^5/_8$- or $^3/_4$-in. tube, 8 in. in length, and a second tube $^5/_8$ in. maximum diameter, 14 in. in length. To solve this problem it was necessary to develop special equipment which was evolved through a compromise of many limiting factors, some dependent upon fundamental photographic principles, and others dependent upon the configuration of the air and food passages. In designing the equipment, the safety of its use in the patient was considered paramount. Ease of manipulation, constant visualization of the field, both during the introduction of the instrument and during the actual photography, axial illumination, and a relatively great depth of field were all considered to be essential features.

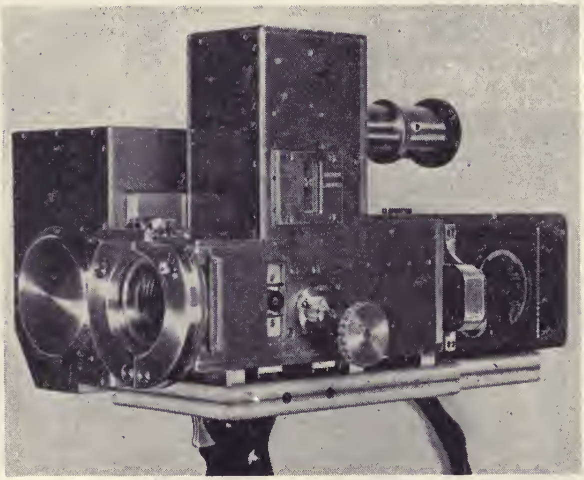


Fig. 1. Left side of camera assembly. The parts, from left to right, are the lamp housing, attaching clamp, glass slide, supplementary lens slot, focusing knob, masks, and the camera box. Above the lens slot and focusing knob are the focus indicator, telescope housing, and eyepiece.

DESCRIPTION OF CAMERA

The new endoscopic motion picture camera is similar in some respects to a type previously constructed.[1–4] The light-source, focusing telescope, and camera are combined in one unit (Figs. 1 and 2). An attaching clamp at the front of the unit permits the instant attachment or detachment of any of several endoscopes or light-reflecting tubes, used to photograph the various areas. A heated removable glass slide placed immediately behind the attaching clamp shields the

optical parts from gross soiling or condensed moisture. The apparatus is held by a built-in handle when the operator is photographing through the endoscopes, or it is supported on a tripod for photography of the larynx by indirect mirror method. The camera is started and stopped by a trigger lever in the handle which also automatically raises the lamp voltage to the proper color temperature while the camera is running. The plane of sharp focus at the object is adjustable and may be placed at any position from 9 to $26^1/_2$ in. from the

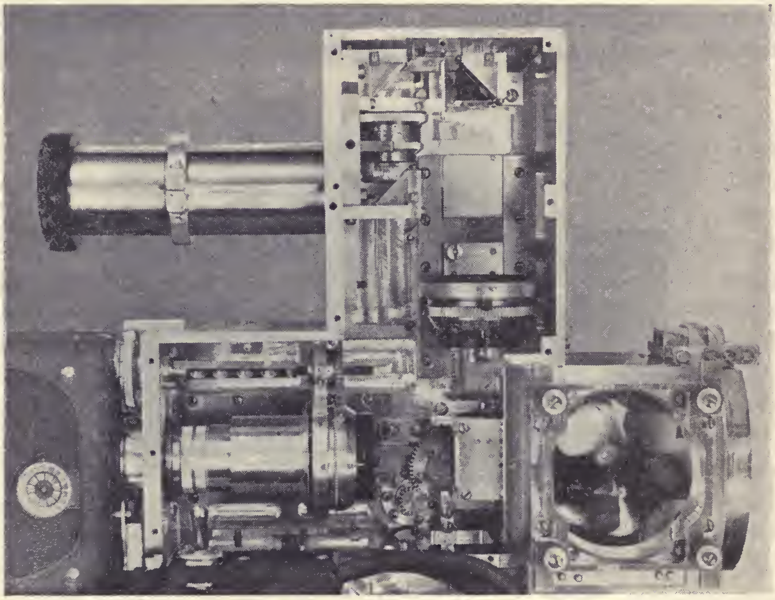


FIG. 2. Interior of camera with cover and lamphouse removed.

attaching clamp. The telescope and camera are focused simultaneously by a knob on the left side of the housing. The telescope shows an exact duplicate of the film image during finding and focusing as well as while the camera is running. A slot permits the insertion of a supplementary achromatic lens of 24.4 cm ($9^5/_8$ in.) focal length for photography of the eardrum at a relatively high magnification.

The endoscopes and light-reflecting tubes are polished and nickel-plated on their inner surfaces. Near the tip of each endoscope the interior surface is threaded for $^1/_2$ in. to help outline the circular field. This is necessary since it is impracticable to arrange the masking

device to mask close to the circular film image. Thus, if the endoscopes are bent slightly during filming, the image is allowed to change position in relation to the mask opening without wandering off the field.

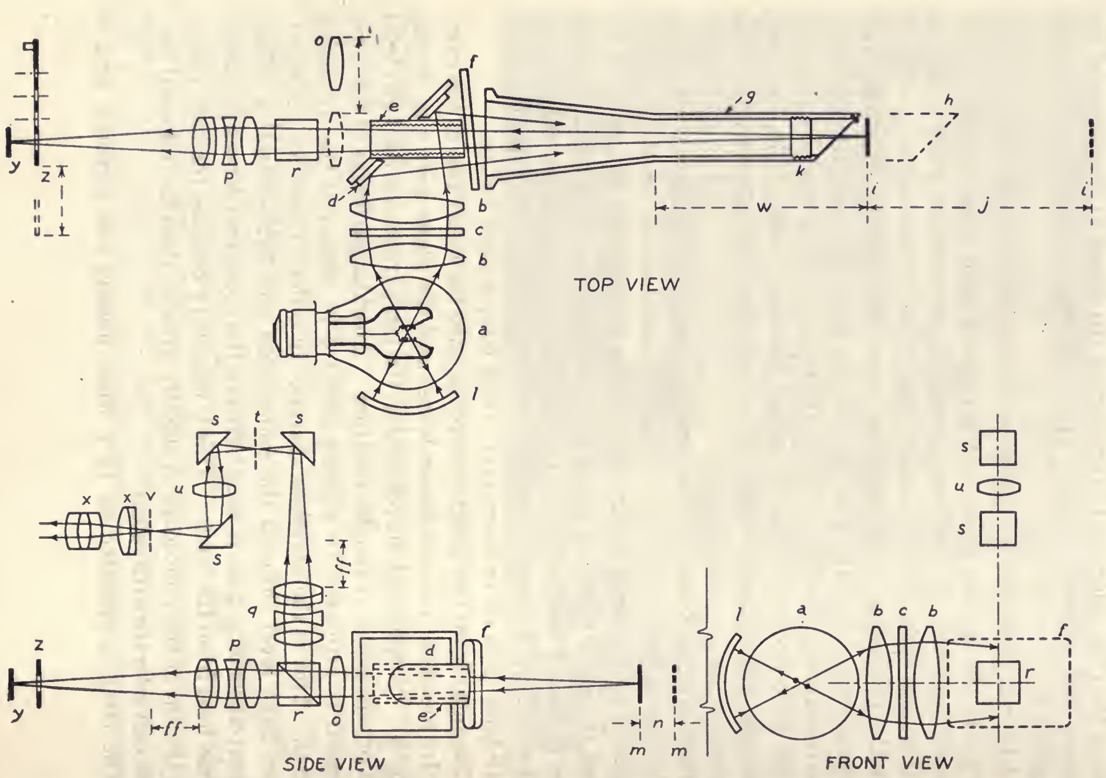
The attaching clamp permits instant attachment or detachment of any of the several endoscopes or light-reflecting tubes. The clamp makes a solid mechanical connection between the endoscope and the camera. The endoscope axis is aligned accurately with the camera axis so that the image of the endoscope tip comes in the center of the camera film aperture, and is approximately centered in the mask opening.

A heated glass slide is used immediately behind the attaching clamp to shield the optical parts of the camera from gross soiling or condensed moisture. A rectangular opening at one side of the front face of the glass slide allows passage of air through the endoscope to permit the patient to breathe freely when the bronchoscope or direct laryngoscope is used. The glass is optically flat and introduces no aberration into the film image. It is placed at an angle of 5 deg to avoid reflections. After the initial heating of the slide, the heat absorbed continuously from the camera lamp bulb keeps the slide warm enough to avoid fogging.

Illuminating System.—An airplane headlight bulb is used as the light source in this camera. It was chosen because its two compact filament coils occupy a very small space about 5 mm square, and because it can be operated on its side instead of in an upright position. The technical description of this airplane tungsten filament lamp is 240 w, 12 v, 20 amp; medium prefocus base; *C-2* type filament; *A-19* bulb ($2^3/_8$ in. in diameter); total lamp length $4^1/_8$ in.

The light from this lamp is directed onto the main axis of the camera by means of two condenser lenses and the plane mirror at 45 deg (Fig. 3). A spherical mirror behind the lamp increases the light level and produces more even illumination. An enlarged image of the lamp filament is projected to a plane about 5 in. ahead of the attaching clamp. This is the optimum distance in order to produce the maximum light level through the endoscopes and light-reflecting tubes. A heat-absorbing glass is used between the condenser lenses to absorb excess heat from the lamp. This is necessary because the heat reaching the tip of the endoscope is slightly greater than the mucosal surfaces can tolerate with safety.

The lamp is operated at 12 v while finding and focusing, and is



(*a*) 240-w airplane headlight lamp, 12 v, 20 amp; (*b*) condenser lenses; (*c*) heat-absorbing glass; (*d*) 45-deg plane mirror; (*e*) tube, threaded on inside; (*f*) optically flat glass slide; (*g*) laryngoscope; (*h*) tip of bronchoscope or esophagoscope; (*i*) plane of sharp focus at object; (*j*) range of focus adjustment (9 to 26½ in. from flange); (*k*) threads on inside of endoscope to produce light ring around image on film; (*l*) spherical mirror; (*m*) object plane in sharp focus when supplementary lens *o* is used; (*n*) range of focus adjustment with supplementary lens (4 to 5 in. from flange); (*o*) achromatic supplementary lens, 24.4 cm. (9⅝ in.) focal length; (*p*) camera lens, *f*/4.5, 90-mm focal length tessar type; (*q*) telescope objective lens, *f*/4.5, 90-mm focal length, tessar type; (*r*) beam-splitter cube, diverts light to telescope focuser; (*s*) front-surface mirrors to bring telescope eyepiece to proper position; (*t*) image plane of telescope objective lens; (*u*) telescope image-erecting lens. A 1-in. focal length, *f*/2.5 movie camera lens is used; (*v*) image plane at eyepiece; (*w*) free working length of laryngoscope; (*x*) eyepiece lenses; (*y*) 16-mm motion picture film in camera; (*z*) movable mask. Four holes shown in top view. (Masks endoscope reflections from film.); (*ff*) focusing motion of camera and telescope-objective lenses.

FIG. 3. Optical system of camera (diagrammatic).

raised automatically to $14^1/_2$ v while the pictures are being taken, by a relay operated by the camera trigger. This produces light of approximately 3450 K, the correct color temperature for type *A* Kodachrome film. The estimated life of the airplane headlight lamp at 12 v is about 50 to 100 hr. When operated at $14^1/_2$ v, the life is about 30 min actual filming time, which permits approximately 750 ft (15 magazines) of film to be taken with one lamp.

Since the endoscopes are polished and nickel-plated on the inside, photographic light intensity of about 160 foot-candles is obtained at the endoscope tip when the lamp is operating at $14^1/_2$ v. This corresponds to a lens setting of $f/8$ at $^1/_{40}$ sec for type *A* Kodachrome film. Since light is absorbed in the glass slide and beam-splitter cube the true stop is about $f/6.8$ at the camera lens when average-colored areas are photographed. When the supplementary lens is used for eardrum photography, the light intensity at the eardrum, through the ear speculum, is about 650 foot-candles, corresponding to a lens setting of $f/16$ when a lens is focused at infinity. The supplementary lens produces an image-to-object ratio of 0.50, and although some light is absorbed in the beam-splitter cube, a marked f stop setting of $f/11$ to $f/16$ can be used. The light distribution at the tip of the endoscope and at the tip of the ear speculum is even, and no image of the lamp filament on the field is noticeable in the finished pictures.

In order to check the actual photographic light intensity at the tip of the endoscopes and light-reflecting tubes, a General Electric exposure meter is used. This permits a periodic over-all check of the proper lamp alignment, lamp blackening, and internal endoscope reflectivity; these factors may affect the proper exposure of the film by causing a reduced light intensity. The meter is used in an empirical manner. The incident-light method is used, with a $^1/_8$-in. hole in an opaque mask covering the photocell. A standard light value is determined by measuring the light intensity at the endoscope tip which produces satisfactorily exposed film, with proper color rendition. A reduction of more than 25 per cent in light value usually requires replacement of the lamp bulb. The light intensity beyond the endoscope tip is uniform enough for satisfactory photography of areas up to about 3 or 4 in. beyond the endoscope tip. For example, a normal level of illumination is obtained at the plane of the larynx when the mirror tube is used. In this case, the photographic field is more than 3 in. from the tip of the light-reflecting tube.

The electrical circuits reaching the camera are at a low voltage and

are well insulated from the 115-v a-c line (Fig. 4). The low-voltage circuits are insulated from the metallic camera housing, and the transformer windings supplying the low voltages are well insulated from the line. With this arrangement, complete safety is provided against electrical shocks to operator or patient.

Optical System.—The basic arrangement allows both the camera lens and the focusing telescope to operate on the same axis, and use the same supplementary lens for higher magnifications. Figs. 2 and 3 illustrate the following discussion.

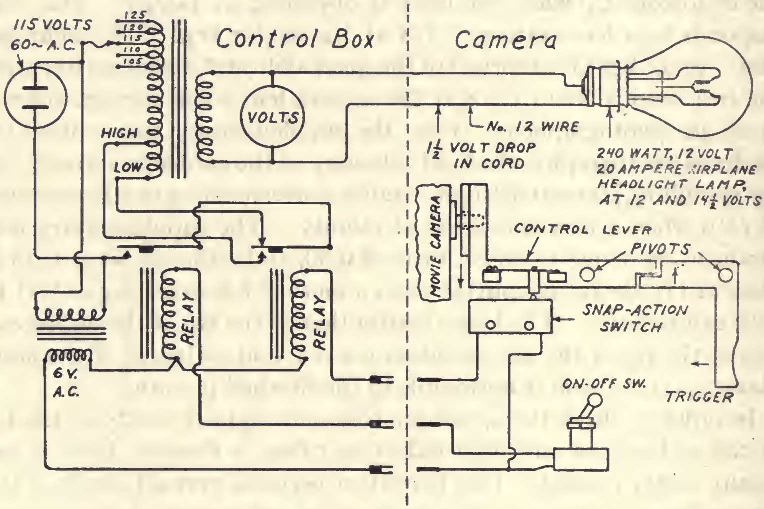


FIG. 4. Electrical and control diagram of camera.

Through the use of a "beam-splitter cube", the camera and focusing telescope view the field at the same time and on the same axis. This beam-splitter cube consists of two right-angle prisms with their hypotenuses cemented together. Before cementing, the hypotenuse of one prism is coated with a very thin partially reflecting aluminum coating. Most of the light reaching the cube passes through it to the camera lens. About 15 per cent of the light is diverted at 90 deg to the telescope objective lens. The camera lens and telescope-objective lens are identical. They are a matched pair of 90-mm focal length Wollensak Velostigmats, Series *2*. The lenses are of exactly equal focal length, and are of $f/4.5$ aperture. They are of the coated type (with antireflection coating) for improved light transmission and improved image contrast. The maximum usable

aperture for both lenses is limited to $f/5.6$ by the dimensions of the beam-splitter cube, and by the tube through the 45-deg mirror.

The two lenses are moved simultaneously by a knob with rack-and-pinion motion, through equal distances, and without any backlash or play in the gearing. Friction holds the focusing knob wherever it is stopped. The distance from each lens to its own focal plane is always identical with that of the other lens. Since the focal planes are fixed in position, the motion of the lenses moves the object plane of sharp focus farther or closer in relation to the attaching clamp, and in this way, the camera lens and telescope are always focused upon the same plane in the object space. The supplementary lens simply shifts both planes of sharp focus a certain distance toward the attaching clamp. With the supplementary lens, the focusing action is basically the same as with the regular endoscopes. The regular focusing range of adjustment is from 9 to $26^1/_2$ in. from the attaching flange. At the supplementary distance, the useful range is from 4 to 5 in. from the flange.

The focusing telescope is an extremely important part of the camera. By means of the telescope, the field at the endoscope tip is constantly under visual supervision, allowing safe manipulation of the endoscope in order to reach the desired field for photography, or for supervision of the field while the endoscope is advanced or withdrawn while filming. The telescope enables the plane of sharp focus for the camera to be placed at any distance beyond the endoscope tip; the plane of sharp focus may be changed while the camera is running. The field is seen at all times during filming as well as before and after the pictures are taken. Experience has shown that the mucosal surfaces of low contrast can be focused upon more accurately by using the aerial image and therefore no ground glass is used at the eyepiece focal plane. The telescope is adjusted to produce correct focus for the camera when the eye is relaxed and focused upon infinity—similar to looking into a microscope. The eyepoint is far enough away from the eyecap to permit the operator to wear glasses. The camera is designed for a right-handed person, and for the right eye at the telescope.

The image in the telescope eyepiece is erect and correct from side to side, the same as though the operator were looking directly into an endoscope. The optical system must provide this correct image, since an inverted or transposed image introduces serious risk of trauma when the endoscope is manipulated. The endoscopist would attempt to move the endoscope tip in the opposite direction to that

desired. In the present camera, the erect image is accomplished by means of an erecting lens, rather than a porro system of prisms. The three prisms *s* shown in Fig. 3 are used as front-surface mirrors; this is done to bend the telescope axis in order to place the eyepiece in the most convenient position. The image seen in the telescope is an exact duplicate of the picture recorded on the film. The total magnification of the field as seen in the telescope eyepiece is about five times for the endoscopes, and about ten times for the supplementary lens distance for eardrum photography.

A focus indicator is provided in a window at the side of the main housing to show the position of the plane of sharp focus ahead of the attaching clamp. The indicator may be moved by the focusing knob to the position marked on the scale corresponding to the endoscope used. Without such an indicator, it would be necessary to move the focusing knob while observing through the telescope with a sterile cloth held just beyond the endoscope tip in order to make the focus setting—a source of annoyance and lost time in the busy operating room. The presetting method by means of the indicator is sure and rapid.

Camera Film Box and Photographic Lens.—The motion picture camera box is a Bell and Howell Auto Load. It is permanently attached to the main housing of the endoscopic camera. The release button is operated by the trigger in the handle. The Auto Load camera uses 16-mm type *A* Kodachrome film in 50-foot prethreaded magazines and runs about $12^1/_2$ ft at one winding. This corresponds to 31 sec of filming time at 16 frames per sec. While the normal shutter speed of the camera is $^1/_{43}$ sec at 16 frames per sec, the shutter-blade opening on this camera was increased to allow the light from the lens to remain on the film for a longer period of time, permitting the use of a slightly smaller *f* stop. The new shutter speed is $^1/_{34}$ sec. This change is possible because the film image is limited to a circle 0.250 in. in diameter. The camera model chosen provides for the choice of 8, 16, 24, or 32 frames per sec. A speed of 16 frames per sec is ordinarily used, but a speed of 24 frames per sec is possible at $f/6.3$ for photography of the larynx where much light is reflected from the photographic field.

A special masking device is built into the left side of the camera film box in order to mask off the out-of-focus images reflected from the inside of the endoscopes (Fig. 3). The mask is a metal strip with a series of four holes of graduated sizes corresponding to the film-image diameter of the various endoscope tips. The largest opening is

0.250 in. in diameter and the strip is moved by a small knob (Fig. 1) to center each hole automatically in the film aperture. The mask is 0.250 in. ahead of the film, and it masks fairly close to the circular film image, with only a small margin of the endoscope wall visible in the finished picture. Without such a mask, the bright out-of-focus images reflected from the inside of the endoscopes would cause confusion when the finished film is viewed.

As previously stated, the camera lens is a 90-mm focal length $f/4.5$ anastigmat type. The maximum usable aperture is $f/5.6$. The f stop is adjusted by a knob at the rear of the main housing. f stops of 5.6, 6.8, 8, 9.5, 11, 13.6, and 16 are provided (one-half stop intervals). The maximum circle of confusion on the film, due to aberrations of the lens, is less than 0.001 in. In other words, a geometric point at the object plane of sharp focus is imaged as a circle smaller than 0.001 in. at the film plane. This is entirely adequate for the best quality motion picture photography on 16-mm Kodachrome film, and is the accepted standard for the best lenses used with 16-mm cameras.

The depth of field (sometimes called depth of focus) at the object plane of sharp focus, is about ± 0.250 in. for a reasonably sharp image. This is for a maximum circle of confusion on the film of 0.004 in. For a good practical value for sharpest possible image, the depth is only about ± 0.125 in. when 0.002 is taken as the circle of confusion. Theoretically it is possible to show details which are imaged as small as 0.001 in. at the film plane, but 0.002 in. is a good working value for best results. Because of the motion of the screen image, occasional short scenes very slightly out of focus detract little from the general effect.

The camera handle is notched to provide a comfortable and secure grip. The index finger is free to operate the trigger camera release. The handle is located so that the center of gravity of the camera is balanced over the hand when the camera axis is tipped forward to 25 deg from the horizontal, the approximate angle of the endoscope when the patient is in the recumbent position for direct peroral endoscopy. A threaded hole for a tripod is located in the bottom of the handle to support the camera while mirror pictures of the larynx are being taken, or when pictures are being taken at the supplementary distance.

TECHNIQUE

The endoscopes are heated to slightly above body temperature by an electric heating pad or by a brief immersion in the sterilizer just

before use. Condensed moisture on the inner surface of the endoscopes would reduce the reflection of photographic light from the lamp. The glass slide for the camera is heated in the lamp housing and the heat from the bulb keeps it warm after it is inserted in the camera. A spare glass slide is available should the slide in the camera become spattered if the patient coughs. An assistant receives the camera from the endoscopist when it is detached from the endoscope to permit cleaning, winding, or changing film. The endoscopes may be introduced into the patient with the camera attached, since the lamp and telescope give full visualization of the field at the endoscope tip. The quick-acting attaching clamp for the endoscopes provides instantaneous release of the camera for aspiration of secretions by suction tube if necessary. In order to observe the endoscopic field when the camera is detached, a light carrier from a standard bronchoscope of proper length is used, held inside the endoscope. Light-carrier canals and suction tubes are not built into the endoscopes since they would encroach upon the circular field and detract from the appearance of the finished film.

While the endoscope is being introduced, the plane of sharp focus is set just beyond the endoscope tip. The moving field is photographed to demonstrate the landmarks seen during the introduction of the various instruments. The plane of sharp focus is then set at a suitable distance ahead of the endoscope tip, and the endoscope slowly advanced or withdrawn with the camera running, in order to show the moving field as seen during an endoscopic examination. In this way, it is possible to take a series of scenes fully simulating a bronchoscopic examination.

Contrary to general opinion, it is more difficult to obtain satisfactory pictures of the vocal cords and larynx by the indirect mirror method than through the direct laryngoscope. The usual technique is to support the camera on a tripod with the light-directing mirror tube attached. The laryngeal mirror may be attached to the mirror tube, or held independently in the operator's hand while the tongue is held out of the way by the patient. The mirror tube is partially inserted into the mouth and acts somewhat as a tongue depressor and prevents the tongue from rising into the photographic field. In the majority of patients, it is difficult to align the camera axis, mirror, and laryngeal axis simultaneously so that a good view is to be had of the larynx. An overhanging epiglottis often obscures the anterior commissure. An additional difficulty is the necessity of obtaining

sharp focus of the vocal cords, arytenoids, and epiglottis, all at the same time. The vocal cords ordinarily are placed in sharp focus and the rest of the field is slightly out of focus, or the area of greatest interest is placed in sharp focus. The general effect is usually satisfactory even though some parts may be out of focus.

OTHER USES

Since the camera described is fundamentally a universal endoscopic type suitable for photographing through almost any of the common open-tube endoscopes or speculums, a brief discussion of its uses in proctology and gynecology is indicated.

For proctology, a sigmoidoscope of 13 in. total length may be used. The largest diameter practicable is recommended in order to obtain a large field. The free working length of $7^3/_4$ in. (20 cm) is satisfactory for most proctoscopic cinematography, and provides a reasonably large image on the film. A free working length of 6 in. (15 cm) is sufficient for much proctoscopic photography, and would provide a larger image on the film. In the latter case, the total endoscope length is $11^1/_4$ in. The simulated perspective effect is seen in proctoscopic cinematography as well as in peroral cinematography. The endoscope is first introduced with an obturator in place. The obturator is then withdrawn, and the field examined with a light stick held inside the sigmoidoscope. After the desired field is located, the camera is attached and the pictures are taken. The bowel wall may be scanned as the endoscope is being withdrawn while filming. Additional descriptions of techniques, and photographic illustrations of proctoscopic views, have been published elsewhere.[3]

For photography of the cervix uteri, light-directing tubes of various diameters are suggested; the maximum diameter usable on this camera is about 1 to $1^1/_4$ in. (2.5 to 3 cm). Since the film area in the camera is limited to $^1/_4$ in., the light-directing tubes must not be shorter than 10 in. total length in order to have the whole object field appear on the film. In this case, the field is planned to be about 13 to 15 in. from the attaching flange of the light-directing tube. The tube diameter should be slightly smaller than the opening in the vaginal speculum, to avoid light reflections from the proximal portion of the speculum blades. The camera with its light-reflecting tube can be aligned externally with the axis of the speculum, and the pictures taken. It may be desirable to provide a short tubular sleeve attached to one blade of the speculum in order to hold the speculum axis in

line with the camera axis. Without the alignment sleeve, it is possible to scan the field slowly when the whole area to be shown cannot be included on one camera field at one time. Scanning may induce a sense of perspective when the films are viewed, especially if the cervix is moved slightly by abdominal palpation.

SUMMARY AND CONCLUSIONS

By means of specially devised camera equipment, it has been possible to photograph the human air and food passages. The pictures, in motion and color, enable the surgeon to record and study the normal anatomy of these areas as well as their diseased states. The films are invaluable for teaching purposes since they show to large groups of students and physicians the surgical field otherwise visible only to one individual. The actions of the vocal cords are shown and inflammatory processes and tumors of the air and food passages are recorded. Of particular interest is the fact that the techniques used to remove pennies, peanuts, and safety pins, as well as other objects from the windpipe and bronchial tubes of children may be demonstrated by motion pictures taken through the bronchoscope as these objects are being removed.

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DISCUSSION

MR. ELMS: I would like to ask whether it would be possible to photograph the inside walls of the stomach?

DR. P. H. HOLINGER: Stomach photography is one of the most interesting of all photographic work in any of the body cavities. Mr. Brubaker will tell you that this camera has been designed so that we can use longer tubes in order to get into the stomach. We haven't done that yet, but photography of the stomach walls is possible in those patients who have direct openings into the stomach. I do not mean to digress medically, but there are many conditions that require that the patient be fed directly through the wall of the abdomen as the food passage has been obstructed by some disease. The stomach walls can be photographed easily through such an opening.

In *Life* magazine several weeks ago you will remember seeing an apparatus used in animals for photography of the stomach wall through such an opening.

What we hope to do before we finish is to go ahead with the photography you are discussing.

MR. ELMS: You cannot photograph without making incisions?

DR. HOLINGER: I won't say that we can't. Our camera has been completed so recently that we haven't had an opportunity to test this feature of it. I think it is possible.

MR. ELMS: Is this equipment available commercially?

DR. HOLINGER: I guess it is if you wish to have it built. I am sure that Mr. Brubaker could go ahead with its construction. As you see, it is a handmade type of apparatus but he could duplicate it.

MR. ELMS: Do you have pictures of the removal of the safety pin?

DR. HOLINGER: We could have shown you the removal of the safety pin but the time did not allow. We could have shown the various methods of closing the safety pin. Frequently we take the pins to the stomach and straighten them and then remove them. Rather than take the time, we showed various types of foreign bodies rather than techniques. To photograph the closing of a safety pin would take longer than we should wish to leave the instruments in the patient.

DR. E. W. KELLOGG: How far from the end of the tube is your first lens and what is the size of the opening of the tube, giving the field size?

DR. HOLINGER: The size of the field was $^5/_8$ in. in the smaller tube and $^3/_4$ of an inch in the larger tube. It is approximately 20 in. from the lens itself.

Photography ahead of the actual tube itself is possible because the light is proximally located and shines down the tube rather than being distally located with the light at the end of the tube; consequently, photography considerably ahead of the tube is possible with the apparatus—about 4 to 6 in.

DR. J. G. BRADLEY: Have you tried to use zirconium as a pin-point light source?

DR. HOLINGER: Yes we have, but there isn't sufficient illumination for the particular purpose that we need. We tried that not only for the actual photography but for the surgical instruments themselves. It just doesn't give us enough. Maybe we didn't have it set up right.

SOUND ABSORPTION AND IMPEDANCE OF ACOUSTICAL MATERIALS*

HALE J. SABINE**

Summary.—*The application of the acoustic-impedance concept to the study of sound absorption has made it possible to explain and predict the performance of acoustical materials more completely. This paper reviews the theoretical and experimental work done on this subject in recent years and cites some applications to the design of commercial materials.*

In the commercial development of acoustical materials over the past forty or fifty years, the aim in general has been to obtain the highest degree of sound absorption consistent with acceptable structural and decorative qualities and reasonable cost. The absorbing characteristics of commercial materials, particularly with respect to frequency, have been co-ordinated fairly well, either by design or fortunate circumstance, with the acoustical requirements of the spaces in which they are used. For example, in the field of noise abatement, it is well known that reduction of the high-frequency components of the average noise produces much greater relief from annoyance than the same reduction of the low frequencies. Accordingly, in the case of materials intended primarily for noise reduction it is not generally attempted to obtain as high absorption at the low frequencies as at the high frequencies. This is an economic advantage in that it permits the use of relatively thin materials and inexpensive constructions. In special situations, such as radio studios or other rooms in which an absorption-frequency characteristic approaching a flat curve is desired, more expensive constructions involving deeper air spaces or thicker materials are usually required.

Until comparatively recently, knowledge of the relation of sound absorptivity to the physical properties of materials has been mostly empirical and qualitative. It has long been known in a general way that the absorptivity, defined as the per cent of incident sound energy absorbed, depends on the porosity, and, particularly at low frequencies, on the thickness of a material. It has been only within the last ten years or so, however, that it has been possible to predict with a fair degree of precision the absorbing characteristics of a material or

* Presented Apr. 21, 1947, at the SMPE Convention in Chicago.

** The Celotex Corporation, Chicago, Ill.

construction in terms of accurately defined and measurable physical properties. This has resulted principally from the application of the concept of acoustic impedance to the phenomenon of sound absorption. Most of the theoretical and experimental work underlying this development is due to P. M. Morse and R. H. Bolt,[1] and to L. L. Beranek.[2, 3, 4] All experimental data given in this paper were obtained by the author.

ACOUSTIC IMPEDANCE AND ABSORPTIVITY

Specific acoustic impedance has been defined, by analogy with the older and more familiar electrical impedance, as the complex ratio of instantaneous sound pressure to instantaneous particle velocity at a given point in a sound wave or system of waves. When applied to the case of an absorbing material, the impedance of the material is taken as the value existing immediately at its surface.* Stated differently, the impedance of a material is the sound pressure required to produce unit velocity of air movement into its surface, and is thus a measure of the degree to which the material impedes the entrance and absorption of sound waves. Following electrical terminology, the impedance Z has magnitude and a phase angle, which may be resolved into the acoustic resistance R representing that component of particle velocity which is in phase with the pressure, and the acoustic reactance X that component which lags or leads the pressure by plus or minus 90 degrees, respectively. In a single free progressive plane wave in air, the impedance is a pure resistance, having a constant value at all points equal to the density of air ρ multiplied by the wave velocity c. This is termed the characteristic impedance, or radiation resistance, of air, and has a value of approximately 41 centimeter-gram-second units. In any type or combination of waves other than a simple plane wave, the impedance in general has a value differing

* Strictly speaking, the impedance at the surface of a material is referred to as the "normal" acoustic impedance, defined as the ratio of pressure to the component of particle velocity which is at right angles to the surface. The value as thus defined is usually independent of the angle of incidence of the sound wave, and when this is true, the normal impedance may be thought of as a constant or fixed property characterizing the acoustical structure at any given frequency. In certain cases the normal impedance does vary with the angle of incidence, as when the spacing of the partitions in an air space behind a porous material is greater than one-half wavelength, thus allowing wave motion in the air space parallel to the surface.

from point to point in magnitude and phase from the characteristic impedance of air. Acoustic impedance is, therefore, usually expressed in relation to the characteristic impedance of air, as $Z/\rho c$.

The relation between the value of impedance existing at the surface of a material and the absorptivity of the surface may be derived by analyzing the pressure and particle velocity relations in the standing-wave system when the sound wave incident on the material combines

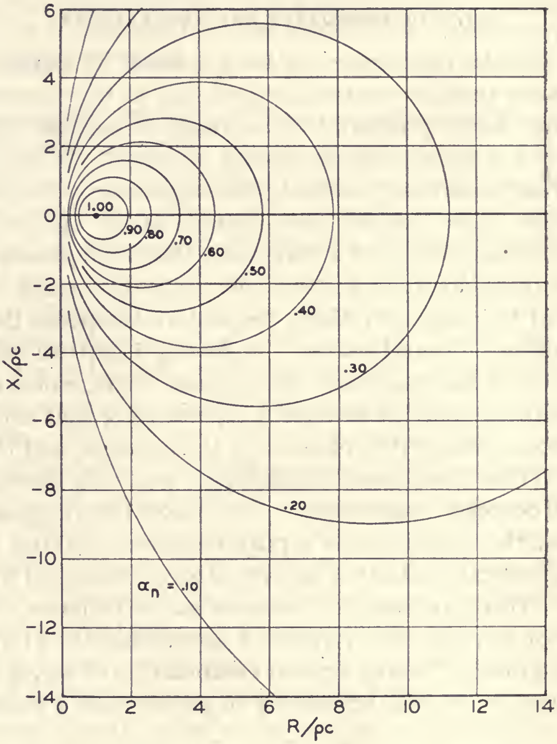


FIG. 1. Relation of normal-incidence absorption coefficient α_n to acoustic impedance $Z = R + jX$.

with the reflected wave of reduced amplitude. For the case of normal or 90-degree incidence of sound waves, the analysis results in the curves of Fig. 1, in which the absorption coefficient α_n is plotted as a family of contours in terms of the two impedance components $R/\rho c$ and $X/\rho c$. The following important points are evident:

(1) A surface having a given absorption coefficient may have any one of an infinite number of impedance values which fall on the

contour corresponding to that coefficient. In other words, the absorption coefficient does not uniquely determine the impedance, but a given impedance does uniquely determine the absorption.

(2) Sound absorptivity depends on how closely the impedance of the absorbing surface matches the characteristic impedance of air. It will be noted that 100 per cent absorption is obtained only when

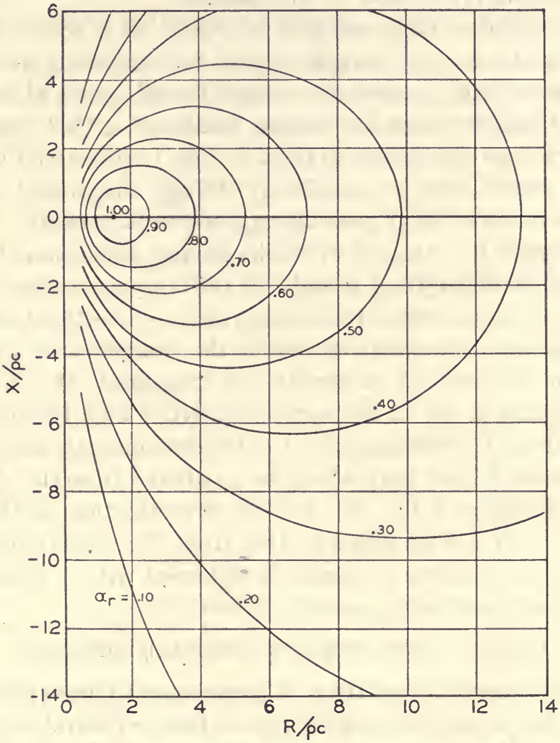


FIG. 2. Relation of random-incidence absorption coefficient α_r to acoustic impedance, based on assumption of completely diffuse sound field.

the impedance match is perfect; that is, when the reactance X is zero, and the resistance R is equal to ρc. It will be shown later that a material surface having this impedance is physically realizable at single frequencies. The effect of acoustic impedance matching is analogous to the well-known electrical case where maximum power transfer results from matching the load impedance to that of the source.

(3) Reducing the magnitude of either positive or negative reactance always increases absorptivity and produces a maximum of absorption at zero reactance. The absorption is always zero, however, at zero acoustic resistance. The physical interpretation of this is the important fact that sound energy can only be absorbed, in the true sense of being transformed into heat energy, by encountering a frictional resistance in the material.

When sound-absorbing material is placed in a room, the sound waves strike it not only at right angles, but randomly at all angles. The absorptivity of a material averaged for all angles of incidence is substantially higher than for normal incidence. This is shown* by Fig. 2 where contours similar to those in Fig. 1 are drawn for the case where the sound field is completely diffuse and sound waves are striking the material at all possible angles simultaneously. This condition is essentially attained in rooms having dimensions large compared to the wavelength of sound and containing average surface irregularities such as normal furnishings and architectural details. In the reverberation chambers in which the published absorption coefficients of commercial materials are measured, the diffuse conditions assumed in Fig. 2 are approximated at high frequencies, but at the middle and low frequencies, limited data indicate that the measured values are higher than would be predicted from the absorption-impedance relation of Fig. 2. Further investigation on this subject is necessary. It will be noted further from Fig. 2 that 100 per cent absorptivity at random incidence is obtained with a value of $R/\rho c$ slightly higher than unity, namely, about 1.4.

ACOUSTIC IMPEDANCE AND PHYSICAL PROPERTIES

Having examined the relation of impedance to absorption, we are now interested in determining the connection between the impedance and the physical properties of an acoustical material and its mounting. Exact formulas have been worked out mathematically[1, 4] for certain cases which give impedance in terms of physical constants, of which some are accurately measurable and others must be assigned estimated values. Experimental work has shown that fairly accurate checks with the theoretical predictions can be made from knowledge of only those physical properties which are directly measurable. In the case of a homogeneous, porous material mounted directly against a rigid backing, these properties are (*1*) thickness; (*2*) porosity P,

* See Fig. 30, p. 141, of Reference 1.

defined as the ratio of the volume of air in the pores of the material to the total volume; and (3) specific flow resistance *r*, defined as the frictional resistance to direct-current air flow offered by unit thickness and area of the material. The flow resistance is determined by the size and configuration of the pores and the fibers or particles forming them.

HOMOGENEOUS POROUS MATERIAL ON RIGID BACKING

The case just referred to is the simplest type of sound-absorbing structure, and being also the most instructive, will be analyzed in some detail. Fig. 3 shows the measured acoustic impedance values

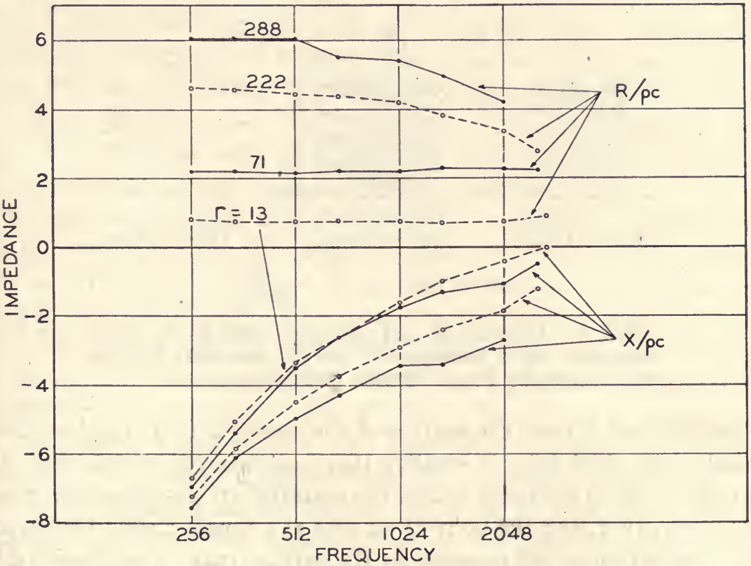


FIG. 3. Measured impedance of one-inch homogeneous porous materials having indicated values of specific flow resistance *r*. Samples tested against rigid backing.

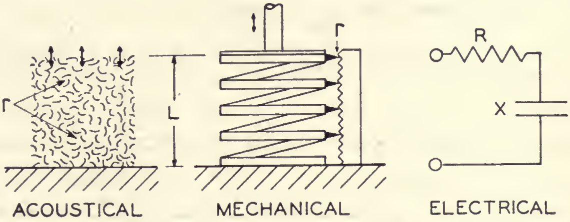
of a series of porous materials all one inch thick, and having varying values of specific flow resistance. The two impedance components are plotted separately against frequency, each pair of *R* and *X* curves representing a single material having the value of flow resistance indicated. The samples are all fibrous, but of varying density and basic material, including glass wool, rock wool, and vegetable fiber. The following points may be observed from these curves:

(1) The acoustic resistance $R/\rho c$ is nearly independent of frequency and is roughly proportional to the direct-current flow resistance of the material.

(2) The acoustic reactance $X/\rho c$ is negative, approximately in inverse proportion to the frequency, and nearly independent of the flow resistance of the material.

(3) A similar set of curves plotted for a different thickness would show that the acoustic resistance increases with the thickness, and that the reactance varies inversely with the thickness.

The physical reasons for these impedance characteristics may be better understood by setting up a mechanical model or analog representing the action of sound pressure on a porous material, as in Fig. 4.



$$R = {}^1/_3 rL. \quad X = -\frac{\rho c^2}{2\pi f P L}$$

FIG. 4. Mechanical and electrical analogs of sound absorption by a homogeneous porous material of thickness L, porosity P, and specific flow resistance r.

If the distance L from the surface of the material to its rigid backing, namely, the thickness, is smaller than one-quarter wavelength, the motions of all air particles within the material are essentially in phase with each other, and the body of air acts as a simple cushion or spring. The alternating sound pressure at the surface may be represented by a vibrating weightless piston. The spring, as is well known, presents a stiffness reactance against the motion of the piston which is negative (velocity leads force), and inversely proportional to the frequency. Reducing the thickness L would be equivalent to making the spring shallower and therefore stiffer, thus increasing the reactance. In addition to the stiffness of the air cushion, the air moving in the pores of the material encounters frictional resistance, or damping, which is essentially independent of frequency and whose value is determined by the pore structure of the particular material. The resistance is represented in the mechanical model by the points

attached to the spring coils engaging the serrated block. The resistance varies directly with the thickness, or, in the mechanical model, with the number of spring coils contacting the resistance block. The frictional resistance and the stiffness reactance in series make up the acoustic impedance of the porous material, or the mechanical impedance of the model. The electrical analog of a capacitor and resistor in series is also shown.

At low frequencies, the impedance of the simple structure shown in Figs. 3 and 4 may be expressed by the following approximations:

$$R \simeq {}^1/_3 rL$$

$$X \simeq -\frac{\rho c^2}{2\pi f P L}.$$

Experimental deviations from these values have been observed and attributed to differences between the static and dynamic values of r and P. In Fig. 3, the fact that with increasing frequencies the resistance $R/\rho c$ deviates from a constant value and that the reactance $X/\rho c$ changes with the resistance is due to the effects of the wavelength becoming smaller in relation to the thickness.

We can now observe how the physical properties of materials are related to sound absorption through impedance by replotting the impedance-frequency curves of Fig. 3 and superimposing them on the impedance-absorptivity contours of Fig. 2. This is done in Fig. 5. Each point represents the measured acoustic resistance and reactance values of a single material at one of the four frequencies indicated, the random-incidence absorption coefficient α_r for each point being given by its position with respect to the absorption contours. The points joined by each vertical line indicate the frequency characteristic of the particular material having the indicated direct-current flow resistance r, and the horizontal lines denote the variation of absorption with flow resistance of the various materials at each frequency. As before, all materials are one inch thick.

From these curves we may derive several useful facts bearing on the practical design of acoustical materials. The securing of high absorption depends on the right combination of both resistance and reactance. In other words, either component alone may be responsible for limiting the absorptivity. For example, knowing that the reactance $X/\rho c$ is governed principally by thickness and frequency, we see from the curves that a one-inch material cannot be expected to have an absorption coefficient at 256 cycles of greater than about 0.35 regardless of its porous structure or flow resistance.

Doubling the frequency to 512 cycles reduces the reactance by approximately one half, and the maximum absorption attainable at this frequency is raised to about 0.53. The same effect could be obtained by doubling the thickness instead of the frequency.

It will be noted further that because of the positions of the absorption contours, the absorption peak occurs at progressively lower values of flow resistance with increasing frequencies. In other words, a material of a given thickness cannot have a value of flow resistance such

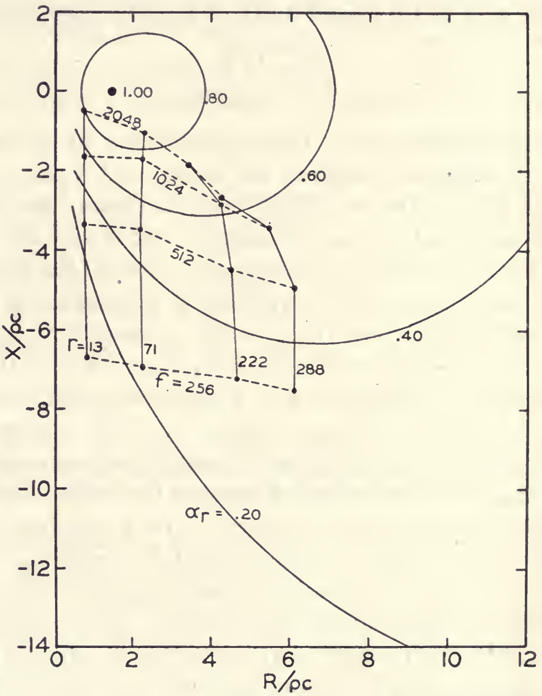


FIG. 5. Data of Fig. 3 shown in relation to contours of random-incidence absorption coefficient α_r.

that the maximum absorption attainable for that thickness is reached at both the high and low frequencies at the same time. This can be shown better by plotting the experimental data of Fig. 5 (plus data for a few additional samples) as curves of absorption coefficient *vs.* flow resistance for each frequency. This is done in Fig. 6, where each vertical row of points represents a separate material. The average coefficient for the particular four frequencies chosen is defined as the Noise-Reduction Coefficient, and its curve is also shown. Materials

with very low flow resistance, such as low-density glass or rock wool, show the widest variation between low- and high-frequency absorption, with less than maximum average absorption. As the flow resistance is increased, the spread between low and high frequencies is reduced and the average absorption rises to a broad peak. With further increases of flow resistance, as in high-density, relatively nonporous boards or tiles, the absorption-frequency characteristic becomes progressively flatter, but at the expense of over-all absorptivity.

The effect of porosity P, defined previously as the ratio of air volume to total volume of a porous material, was not considered in the

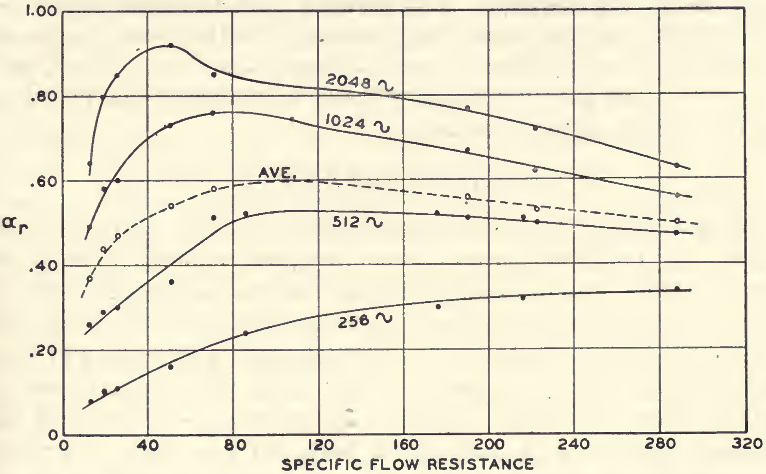


FIG. 6. Relation of random-incidence absorption coefficient α_r to specific flow resistance of one-inch homogeneous porous materials on rigid backing. Data taken from impedance measurements.

foregoing analysis of experimental data. Since the stiffness of the air in the pores of a material depends on the air volume alone rather than the gross volume of air and material, the reactance is determined by the "effective" thickness which is the actual thickness multiplied by the porosity. Measurements by Beranek[4] have shown that practically all fibrous materials having usable sound absorption have porosities of more than 85 per cent and that the porosity varies much less between materials than the flow resistance. In the materials, all of them fibrous, for which the above test data were determined, the porosity enters only as a minor factor which does not greatly affect the absorption nor cause appreciable deviation of the experimental

points from a smooth curve. Materials composed of very coarse shreds or of solid particles bonded together may have porosities ranging as low as 30 or 40 per cent, and the maximum absorption of which they are capable is limited by effective thicknesses which are less than their actual thickness by these ratios.

Summing up the characteristics of the simplest type of sound-absorbing structure as heretofore analyzed, it may be stated as a first approximation that at low frequencies the absorption is limited by the reactive component of impedance which in turn is governed by the thickness, and that at high frequencies the absorption is controlled by the resistive component of impedance which depends on the flow resistance of the material. This explains what has been known experimentally for many years, that increasing the thickness of a porous material increases the low-frequency absorption and, so to speak, progressively lowers the low-frequency cutoff, without appreciably changing the high-frequency absorption.

EFFECT OF AIR SPACE

The next simplest type of acoustical structure, and one of the most common, is the homogeneous porous material mounted with an air space between it and a rigid backing. The well-known effect of this mounting in increasing the low-frequency absorption may be caused by either or both of two factors, namely, increase of the effective thickness and diaphragmatic vibration. Neglecting the latter and assuming that there is no rigid, impervious layer which would restrict the vibratory motion of air through the back of the material, the interposing of the air space provides a deeper and therefore softer air cushion between the outer face of the material and the rigid backing. This results in lowered acoustic reactance and higher absorption in the frequency region where the absorption is reactance controlled. The deeper the air space, the lower the frequencies at which effective absorption increases occur. Thus the very practical point is brought out that increased absorption at low frequencies can be obtained only by increasing the total space between the face of the treatment and the rigid backing, but that most of the space need be occupied only by inexpensive air rather than costly acoustical material. This is taken advantage of in the hanging of drapes for acoustical purposes. When hung in close contact with the wall they have high absorption only at the very high frequencies. By spacing them out a foot or two, the curve can be flattened out over a large part of the frequency range.

When materials of the board-type are light enough and flexible enough to vibrate diaphragmatically when mounted over an air space, the absorption depends both on the motion of air into the pores and the motion of the material surface itself. The introduction of the three additional constants governing the diaphragmatic vibration of the material, namely, its mass, its flexural stiffness, including that of its attachment to the supporting members, and the frictional resistance to bending set up in the material and its supports, result in a rather complicated over-all impedance function. The limited studies carried out so far indicate that appreciable increases in absorption by diaphragmatic vibration of highly porous materials occur only at mechanical resonance frequencies, and then only when the mechanical constants are such as to produce a sharp, well-defined resonance peak.

ABSORPTION BY DIAPHRAGMATIC VIBRATION

Diaphragmatic absorption is much simplified if the material is non-porous. In this case the motion of its surface, when it vibrates as a whole, is that of a mass supported by a spring whose total stiffness is the sum of that of the air cushion under the diaphragm, and the flexural stiffness of the diaphragm and its supports. The diaphragm exhibits the usual resonant frequency determined by the ratio of stiffness to mass. The acoustic impedance of a diaphragm is simply the mechanical impedance per unit area. At the resonant frequency the negative acoustic reactance caused by stiffness equals the positive reactance due to the mass of the diaphragm, resulting in a net acoustic reactance $X/\rho c$ equal to zero. From the absorption-impedance relations shown in Fig. 2, we know that the absorption will reach a peak at the resonant frequency, and that the height of this peak will depend only on the acoustic resistance $R/\rho c$. The acoustic resistance in turn is given directly by the mechanical frictional resistance set up in the bending of the material. As in the case of porous materials, the acoustic resistance of a diaphragm can be too low as well as too high for maximum possible absorption. Many attempts at developing vibratile acoustical materials have been made on the assumption that vibration alone is sufficient for high absorption. Materials such as thin metal or hard paper, for example, while they may vibrate quite freely in a sound field, have internal bending resistances which are much too low to provide the proper match with the characteristic impedance of air ρc. In other words, since there is not enough frictional resistance to transform more than a small percentage

of incident sound energy into heat, the rest must necessarily remain as sound in a reflected wave.

The curved panels of thin plywood, used as diffusing elements in radio studios and sound stages, furnish a good example of diaphragmatic absorption. By varying the depth of the air spaces and the spacing of the supports, the resonant frequencies are staggered over a wide range. Still higher resonant frequencies are obtained through segmental vibration of the panels. The resultant average absorption curve is therefore quite smooth but of comparatively low value.

PERFORATED FACING OVER POROUS MATERIAL

One of the most common variations of the above-described elementary types of acoustical material is the provision of a perforated rigid plate such as asbestos cement board over a porous material. From standard acoustical theory we find that for wavelengths larger than the dimensions or spacing of the perforations, the acoustic impedance of such a plate is essentially a pure positive reactance (with a negligibly small resistive component) which increases with the frequency and with the thickness of the plate and is inversely proportional to the per cent of plate area occupied by the perforations. At low frequencies its value is given by

$$X = \frac{2\pi f\rho(l+\pi D/4)}{k}$$

where l is the thickness of the plate, D is the diameter of the perforations, and k is the per cent of open area.[5]

Fig. 7 shows the measured impedance and the corresponding theoretical random-incidence absorption values of a one-inch sample of porous material having a specific flow resistance of 19, with and without a rigid facing which is $^3/_{16}$ inch thick, perforated with $^3/_{16}$-inch diameter holes, $^{17}/_{32}$ inch on centers, and spaced out $^1/_{16}$ inch from the porous material. At low frequencies the positive reactance of the plate is so small compared to the negative reactance of the air in the material that the presence of the plate has no appreciable effect on the absorption. With increasing frequencies the positive reactance of the plate becomes increasingly large with relation to the negative reactance of the air behind it until a resonance frequency is reached at which the net reactance is zero. At this frequency the absorption is considerably increased over that of the material without the perforated covering. It is determined by the resistive component alone, which, as has been seen before, depends on

the flow resistance of the material. Above the resonant frequency the reactance increases, being controlled almost entirely by the positive reactance of the perforated plate, and the absorption drops off. With frequencies higher than the range shown in Fig. 7 the wavelength would become comparable to the dimensions of the structure and the impedance could no longer be considered as due to lumped elements. The absorption would not continue to decrease but would tend to fluctuate about some low value.

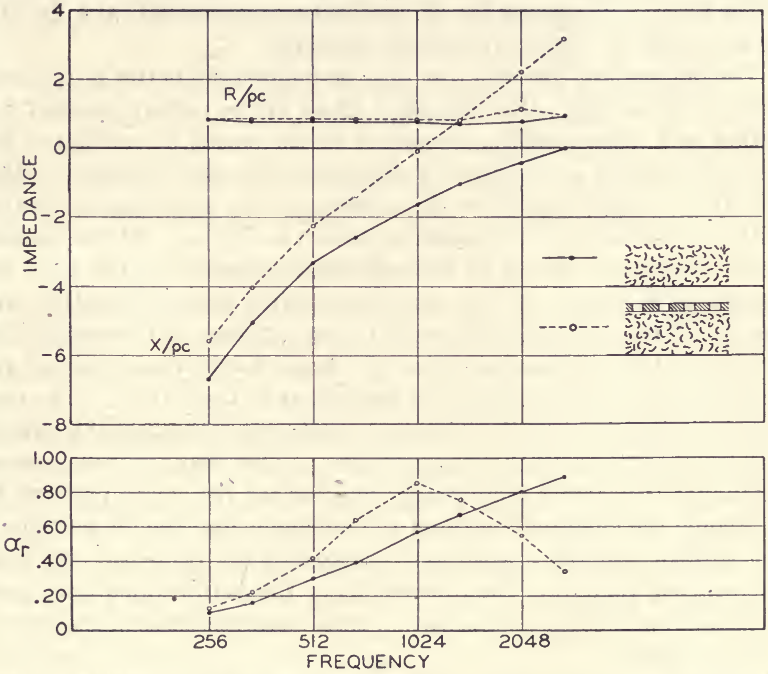


FIG. 7. Measured impedance and absorption of one-inch porous material with and without perforated facing.

It may be noted that at the resonant frequency the reactance is zero, thus fulfilling one of the requirements for 100 per cent sound absorptivity. The other requirement may be met simply by choosing a flow resistance of the material such that the acoustic resistance divided by ρc equals about 1.4 for random angle of incidence, or 1 for normal incidence. As mentioned earlier, perfect impedance matching and the resulting 100 per cent sound absorption can thus be physically realized.

If the flow resistance of the porous element is not too high nor the wavelength too short, the resonant frequency at which the absorption reaches a maximum can be calculated quite accurately from the dimensions of the perforated plate and the air space behind it. This frequency rises with increasing hole spacing and plate thickness and with decreasing hole diameter and depth of air space. The drop-off of absorption both above and below the resonant peak is quite pronounced for the particular structure shown in Fig. 7. A higher flow resistance would have resulted in increased absorption on both sides of the peak. Increasing the thickness, however, would raise the absorption only at frequencies below resonance.

The behavior of the structure may be understood better if it is considered, by analogy, that the plugs of air in the perforations act together as a mass which is supported by the spring or cushion of air behind the plate, forming a simple series-resonant system. (The electrical analogy would be the addition of an inductance in series with the resistance and capacitance shown in Fig. 4.) At frequencies below resonance, the air in the holes moves freely and the total air motion at the outer surface, and the resulting sound absorption, are restricted mainly by the stiffness of the air cushion. At resonance the air plugs find their natural period of vibration with the air spring, resulting in large amplitudes of air movement at the surface. The motion is limited only by the frictional resistance of the porous material and the absorption reaches a maximum. As the frequency rises above resonance it becomes increasingly difficult for the sound pressure to overcome the effective inertia of the air plugs, and the air motion at the surface and the absorption correspondingly decrease. At high frequencies, therefore, the dimensions of the perforations have considerably more effect on absorption than characteristics of the underlying structure.

In practical constructions involving perforated covering plates, the size and spacing of the perforations are necessarily dictated by requirements of appearance, paintability, light reflection, and structural qualities, as well as by absorption characteristics. This compromise sometimes results in losses of high-frequency absorption which may be too high for certain requirements. This condition may be corrected by the use of drapes or fabrics hung close to the wall so as to furnish high absorption at only the high frequencies, or by substituting a perforated board which is either thinner or has a larger per cent of open area.

Since the acoustical behavior of a perforated plate is equivalent (at

low frequencies) to that of a mass, it would be expected that similar results could be obtained by placing an impervious membrane having a definite mass but negligible stiffness and internal bending resistance over a porous material. This proves to be the case, and in practice such membranes are used for various purposes. For example, an impervious paper wrapping over an absorbent element will prevent dusting and the depositing of dirt by direct air flow, but if it is made light enough its acoustic reactance will be so low over the usual frequency range that sound absorption will not be impaired. Heavier membranes such as building felt or paper can be used over porous materials to secure resonances and absorption peaks at definite frequencies and to reduce high-frequency absorption when desired. In one specialized type of treatment commercially available for studios, a number of such membranes of varying weight are alternated with porous materials to secure overlapping resonance peaks and resulting high absorption over an unusually wide frequency range.

INTEGRALLY PERFORATED MATERIALS

Probably the most widely used general class of commercial acoustical materials is the integral porous tile having a painted or otherwise impervious surface with numerous openings in the form of perforations, slots, or fissures which allow access of sound to the porous interior. Analysis of measurements on this type of material show that their action is essentially the same as that of the homogeneous porous material faced with a separate perforated plate as described above. The plate in this case, being simply the impervious coating, has negligible thickness, and the positive or mass reactance due to the openings through it can be predicted from the standard expressions for apertures in an infinitely thin plate. The negative or stiffness reactance is, as before, given by the total volume of air between the face and the rigid backing. The acoustic resistance depends not only on the flow resistance of the porous body of the material, but also to varying degrees on the size and depth of the openings. Moreover, in felted fibrous materials the fibers lie in planes parallel to the surface, with the result that the flow resistance, except for extremely loose, open structures, is much lower in the lateral direction than transversely. Absorption of sound takes place almost entirely through air moving in pores which are parallel to the surface and which communicate with the outside only through the walls of the perforations or slots. The acoustic resistance and the absorption,

therefore, depend on what may be termed "lateral" flow resistance, as distinguished from "transverse". The lateral flow resistance in turn depends inversely on the interior surface area of the perforations. Thus the acoustic resistance of a perforated material may be controlled not only by choice of the basic fiber structure but by the number, depth, and diameter of the perforations or openings. Here again, the total range of possible absorption characteristics obtainable by these and other variables is to some extent limited in practice by considerations of appearance, maintenance, and structural qualities.

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DISCUSSION

DR. E. W. KELLOGG: There are two questions that I want to ask. Does it sometimes occur that a certain space, with a certain total available thickness, gives more absorption by a small space plus a spaced-out thickness of absorbent material than if you filled it up solid with absorbent material?

The other had to do with the absorption by panels. I was discussing it with one of our members and the question arose in our minds whether you can gauge what you might call the frictional coefficient for material by taking a sample and hitting it with your fingers or a stick and observing the duration of the ring it will give. Is it fair to form any judgment as a rather violent movement would be produced by a stick as compared with the very small movement that would take place in wall panels?

MR. HALE J. SABINE: The answer to the first question is that the difference in absorption depends on the flow resistance of the particular material used. If thin material is used it generally has to have a higher specific flow resistance than a material which fills the entire cavity, if the absorption is to be the same.

The answer to the second question—tapping a vibratile membrane does excite its motion in much the same way that sound waves would. The ringing or the duration of the noise which is produced by the tapping is a fair measure of the damping properties. If it gives off a dull thud it has high damping properties. If it gives off a long, pronounced ring, the damping is probably too low for sound absorption. As a matter of fact, it would take a lot of experience correlated with measurements to be able to judge the absorption qualities very accurately by that means, but roughly it is a proper indication.

REPORT OF THE STUDIO LIGHTING COMMITTEE*

The adverse effects on motion picture set lighting because of inadequate wiring or unbalanced load distribution have not been previously emphasized in these reports. Under certain conditions of power distribution, the incoming set voltage at a given lamp may vary from as low as 100 v to the output voltage of the generator, which is usually 120 v, and in extreme cases the voltage on one leg of the 3-wire system actually may be higher than the generator output voltage. It is the purpose of this report to describe motion picture set power-distribution methods and to illustrate the necessity of adequate cable capacity and balanced loads.

In motion picture studio practice the main motor generators supplying power for set lighting are usually located in a central powerhouse and permanent cable is strung to the "bull" switches of the various sets. If the lighting load on a given set is sufficient to cause considerable line drop from the permanent installation, portable motor generators are sometimes placed outside the set to take care of the overload. In other cases, however, particularly where the set is located at a distance from the powerhouse and is cabled for average loads, a considerable voltage drop in the line from the powerhouse to the set is encountered when the lighting load is heavy.

A much more serious problem in voltage drop is encountered on the set where the 3-wire is strung from the "bull" switches all over the area of the stage to spots where lamps have been placed. These installations are of a very temporary nature and the load is constantly changing because of requirements of the director of cinematography as to light levels, balance, and changes from long shot to medium shot to close-up.

An ideal condition exists where the load is known, remains constant, and the installation is carefully balanced and checked with proper instruments. In practice, this ideal is seldom attained. Usually the chief set electrician balances and rebalances the load from knowledge gained through experience. In general, he knows the current each lamp will draw from the line and he supervises the installation for equal load on each side of the 3-wire and decides upon the number of cables which must be paralleled to ensure a minimum of line loss. Too often the pressure of high-speed operation results in serious line loss and unbalanced loads.

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* Submitted Oct. 25, 1946.

Two types of circuits are used in motion picture set lighting for direct-current load.

(1) A simple 2-wire type, shown in Fig. 1, which in actual studio practice is found only on locations where the power is supplied from 2-wire, gas-engine-driven generators.

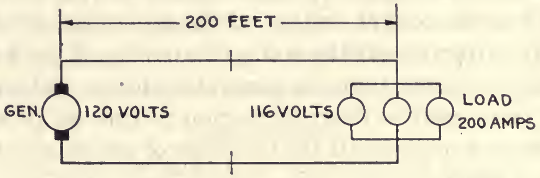

FIG. 1. Single 4/0 feeders connected in series.

(2) By far the largest part of the distribution of power is by the Edison 3-wire system, a diagram of which is shown in Fig. 2. In this system two generators are connected in series; that is, the positive terminal of one generator is connected to the negative terminal of a second generator. The point at which the generators are connected is called a "neutral." In this circuit each generator delivers its normal voltage to the load between the neutral and the "outside" leg as shown in the diagram.

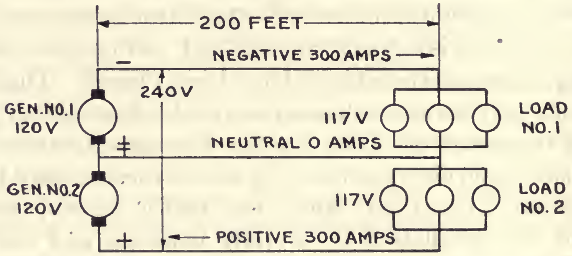

FIG. 2. Balanced circuit, single 4/0 feeders connected in series.

In this discussion the current will be considered to flow in accordance with the electron theory which is that the current or electrons flow from the negative terminal through the load and back to the generator through the positive terminal.

Where the load is exactly balanced no current flows in the neutral, but where the load is unbalanced the current through the neutral is equal to the difference between the current in the two outside legs.

In the case of the balanced load, as outlined above, the current would flow from the negative terminal of generator No. 1 through the negative lead, through load No. 1, and then through the cable connecting load No. 1 to load No. 2, through load No. 2 back to the positive terminal of generator No. 2. Should the circuit become unbalanced, as shown in Fig. 3, then all of the current would flow through the negative lead, through load No. 1 to the neutral point, where part of the current would flow back to the neutral point between the two generators, and then to generator No. 1. The balance of the current would flow through load No. 2 and back to the positive terminal of generator No. 2.

It is possible in extreme conditions of unbalance to have the voltage applied to one load greater than the generator voltage. This can

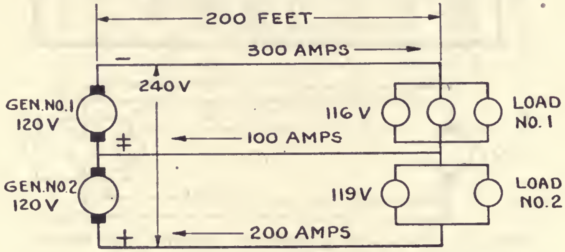

FIG. 3. Unbalanced circuit, single 4/0 feeders connected in series.

happen where the loss in the neutral is greater than the loss in the outside conductor which is carrying the least load; a condition which is sometimes found on sets where a single neutral is used on a long run and the outside lines have been doubled up by using several extra conductors. Cases have been known where the voltage on one side of the line at the set was 15 v above that at the generator, causing incandescent lamps to burn out and carbon arcs to become unstable from overload.

This condition may probably become clearer if we consider the circuit shown in Fig. 3 *with the neutral disconnected.* We would then have load No. 1 and load No. 2 with the two outside leads connected in series across the 240 v of the two generators.

By the use of Ohm's law we find the resistance of load No. 1 to be 0.387 ohm and the resistance of load No. 2 is 0.595 ohm. To these figures should be added the resistance of the cables which would then be $0.01 + 0.01 + 0.387 + 0.595 = 1.002$ ohms total resistance. The

Two types of circuits are used in motion picture set lighting for direct-current load.

(1) A simple 2-wire type, shown in Fig. 1, which in actual studio practice is found only on locations where the power is supplied from 2-wire, gas-engine-driven generators.

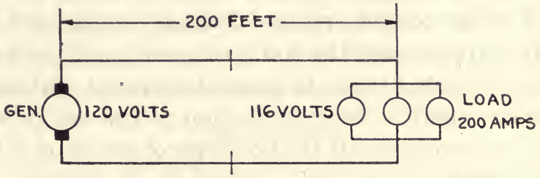

FIG. 1. Single 4/0 feeders connected in series.

(2) By far the largest part of the distribution of power is by the Edison 3-wire system, a diagram of which is shown in Fig. 2. In this system two generators are connected in series; that is, the positive terminal of one generator is connected to the negative terminal of a second generator. The point at which the generators are connected is called a "neutral." In this circuit each generator delivers its normal voltage to the load between the neutral and the "outside" leg as shown in the diagram.

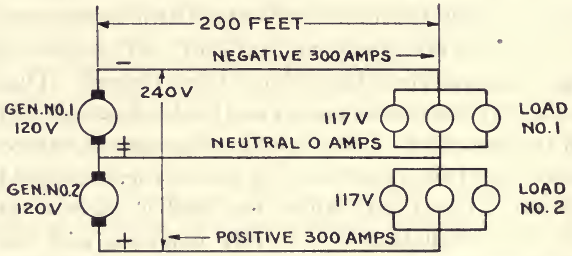

FIG. 2. Balanced circuit, single 4/0 feeders connected in series.

In this discussion the current will be considered to flow in accordance with the electron theory which is that the current or electrons flow from the negative terminal through the load and back to the generator through the positive terminal.

Where the load is exactly balanced no current flows in the neutral, but where the load is unbalanced the current through the neutral is equal to the difference between the current in the two outside legs.

In the case of the balanced load, as outlined above, the current would flow from the negative terminal of generator No. 1 through the negative lead, through load No. 1, and then through the cable connecting load No. 1 to load No. 2, through load No. 2 back to the positive terminal of generator No. 2. Should the circuit become unbalanced, as shown in Fig. 3, then all of the current would flow through the negative lead, through load No. 1 to the neutral point, where part of the current would flow back to the neutral point between the two generators, and then to generator No. 1. The balance of the current would flow through load No. 2 and back to the positive terminal of generator No. 2.

It is possible in extreme conditions of unbalance to have the voltage applied to one load greater than the generator voltage. This can

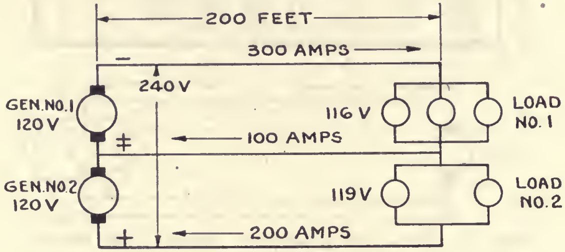

FIG. 3. Unbalanced circuit, single 4/0 feeders connected in series.

happen where the loss in the neutral is greater than the loss in the outside conductor which is carrying the least load; a condition which is sometimes found on sets where a single neutral is used on a long run and the outside lines have been doubled up by using several extra conductors. Cases have been known where the voltage on one side of the line at the set was 15 v above that at the generator, causing incandescent lamps to burn out and carbon arcs to become unstable from overload.

This condition may probably become clearer if we consider the circuit shown in Fig. 3 *with the neutral disconnected.* We would then have load No. 1 and load No. 2 with the two outside leads connected in series across the 240 v of the two generators.

By the use of Ohm's law we find the resistance of load No. 1 to be 0.387 ohm and the resistance of load No. 2 is 0.595 ohm. To these figures should be added the resistance of the cables which would then be $0.01 + 0.01 + 0.387 + 0.595 = 1.002$ ohms total resistance. The

total current which would flow through the circuit under this condition would be 240/1.002 = 239.5 amp. Therefore the voltage drop across load No. 1 would be 239.5 × 0.387 = 92.7 v. The voltage drop across load No. 2 would be 239.5 × 0.595 = 1425 v.

FIG. 4. Two-wire generator—single 4/0 feeders.
Voltage at the set.

Amperes: Load	Distance in Feet: 100	200	300	400	500	600	700	800
100	119	118	117	116	115	114	113	112
200	118	116	114	112	110	108	106	
300	117	114	111	108	105	102		
400	116	112	108	104	100			

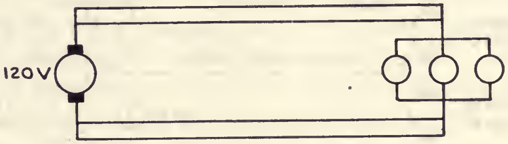

FIG. 5. Two-wire generator—double 4/0 feeders.
Voltage at the set.

Amperes: Load	Distance in Feet: 100	200	300	400	500	600	700	800
100	120	119	119	118	118	117	117	116
200	119	118	117	116	115	114	113	112
300	118	117	115	114	112	111	109	108
400	118	116	114	112	110	108	106	
500	117	115	112	110	107	105		
600	117	114	111	108	105			
700	116	113	109	106				
800	116	112	108					

The foregoing would be the result if the neutral were disconnected as mentioned above. If the neutral were reconnected to the circuit through a high variable resistance there would be little change in the condition shown. However, if the resistance in the neutral were lowered until reduced to the resistance of 200 ft of 4/0 cable, the circuit would be brought back to the conditions shown in Fig. 3.

The line loss in a 3-wire circuit is much less than in a 2-wire circuit carrying the same load, which will be seen from the following example. If we were to connect the 600-amp load shown in Fig. 2 to a 2-wire

circuit of single 4/0 cable (this would be much beyond the capacity of single 4/0 and is used merely for illustration), then the voltage at the

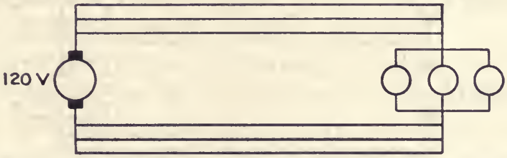

FIG. 6. Two-wire generator—triple 4/0 feeders. Voltage at the set.

Load (Amperes)	Distance in Feet: 100	200	300	400	500	600	700	800
100	120	119	119	119	118	118	118	117
200	119	119	118	117	117	116	115	115
300	119	118	117	116	115	114	113	112
400	119	117	116	115	113	112	110	109
500	118	117	115	113	111	110	108	106
600	118	116	114	112	110	108	106	104
700	118	115	113	110	108	106	103	101
800	117	115	112	109	106	104	101	
900	117	114	111	108	105	102		
1000	117	113	110	106	103			

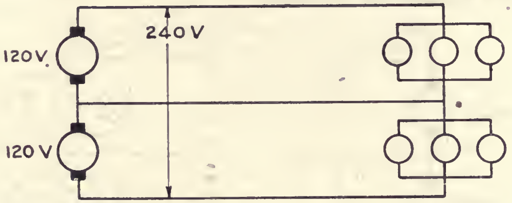

FIG. 7. Three-wire generators—single 4/0 feeders. Voltage at the set.

Load (Amperes at 240 v)	Distance in Feet: 100	200	300	400	500	600	700	800
100	120	119	118	118	117	117	116	116
200	119	118	117	116	115	114	113	112
300	118	117	115	114	112	111	109	108
400	118	116	114	112	110	108	106	104

load would be as follows: The total resistance of the line would be 0.02 ohm and the total current 600 amp. The line loss would then be $600 \times 0.02 = 12$ v. Compare this to the line loss of 3 volts shown in Fig. 2.

Another important principle is that the line loss is reduced in proportion to the square of the increase in voltage. In the 3-wire circuits given above, while we have 120 v at the generators and apply this voltage to the load, the actual voltage of transmission is 240 v. Figs. 4 to 9 show voltages set under varying load conditions. Table 1

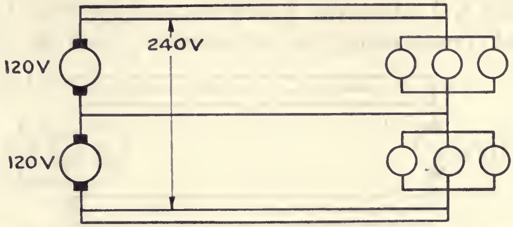

FIG. 8. Three-wire generators—double 4/0 feeders. Voltage at the set.

Load (Amperes at 240 v)	Distance in Feet 100	200	300	400	500	600	700	800
100	120	120	119	119	119	118	118	118
200	120	119	118	118	117	117	116	116
300	119	118	118	117	116	115	115	114
400	119	118	117	116	115	114	113	112
500	119	117	116	115	114	112	111	110
600	118	117	116	114	113	112	110	109
700	118	116	115	113	111	109	108	106
800	118	116	114	112	110	108	106	104

shows the carrying capacity of the copper wire ordinarily used in motion picture studio set lighting.

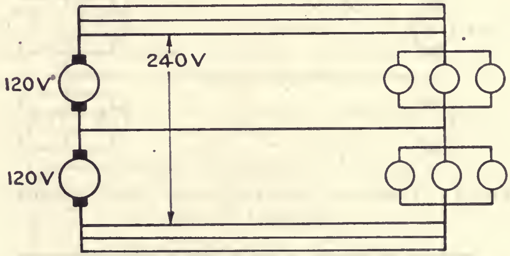

FIG. 9. Three-wire generators—triple 4/0 feeders. Voltage at the set.

Load (Amperes at 240 v)	Distance in Feet 100	200	300	400	500	600	700	800
100	120	120	120	119	119	119	119	119
200	120	119	119	119	118	118	118	117
300	120	119	118	118	117	117	116	116
400	119	119	118	117	117	116	115	115
500	119	118	117	117	116	116	115	114
600	119	118	117	116	115	114	113	112
700	119	118	116	115	114	113	112	111
800	119	117	116	115	113	112	111	109
900	118	117	115	114	112	111	109	108
1000	118	117	115	113	111	110	108	106

EFFECTS OF VARYING LINE VOLTAGES ON CARBON-ARC LAMPS

Light Output.—Table 2 shows that an extreme case of a drop from a normal "on-set" voltage of 115 to 100 v would theoretically result in

a light loss to 55 per cent of normal. While an increase of from 115 to 125 v would theorotically result in a gain to 125 per cent of the light, such an extreme change would cause severe unsteadiness because of the rise in current from 149 to 170 amp.

However, in actual practice the variation in light is much less than indicated by Table 2. In motion picture studio set lighting carbon-arc lamps, the positive-negative carbon feed ratio is fixed and is based on an average of 115 line volts at the lamp ballast. The arc-control

TABLE 1

Copper Wire

Size AWG	Dia in Mils	Ohms per 1000 Ft	Ampere Rating: Underwriters	Ampere Rating: Manufacturers Type *RH*
4/0	460	0.050	225	358
2/0	365	0.078	150	267
2	258	0.156	90	170
4	204	0.248	70	125
6	162	0.395	50	94
8	128	0.628	35	69
10	102	1.000	25	50
12	80	1.588	20	37
14	64	2.525	15	29

TABLE 2

Effect of Varying the Line Voltage

NOTE: In this test a Type *170* high-intensity arc was operated with its trim at all times in normal relation, *i. e.*, with $1^5/_{16}$ in. protrusion and $^1/_2$ in. gap. The voltage was varied and readings were taken at the conclusion of a 3-min burning period at each successive voltage.

	Line Volts	Current	Arc Volts	Light
Line volts decreased	100	128	53	55
	105	134	57	74
	110	140	59	88
	*115	149	62	100
Line volts increased	120	159	63	112
	125	170	64	125

* This is normal operation.

motors are nstalled in such a manner that when the lamps are in operation, the motors are energized by current at arc voltage. If the lamp is undervolted the burning rate of the carbons will decrease and they will tend to feed together, but as they approach each other the arc is shortened and the arc voltage drops. Since the motor is energized at arc voltage, it will rotate more slowly on its reduced voltage and lower the feed rate. In this manner a balance automatically

is attained between carbon burning rate, arc voltage, feed motor speed, and carbon feed rate, *providing the voltage to the lamp is held to close limits.* If the voltage to the lamp varies more than approximately ± 5 v, a number of difficulties are encountered.

Low line voltage will result in less current flowing through the arc and inasmuch as the burning rate of the positive carbon decreases with lower current in greater proportion than the burning rate of the negative carbon, the protrusion of the positive carbon will increase unless a manual adjustment is made. Table 3 shows the effects of varying protrusion.

TABLE 3

Effect of Varying the Protrusion

NOTE: A M-R Type *170* high-intensity arc was used on 115 line volts. The negative was kept in the normal position, *i. e.*, that which it assumed with a normal $1/2$ in. gap and $1\,5/16$ in. protrusion. The positive carbon was successively moved and allowed to burn 3 min in each position.

	Protrusion	Current	Arc Volts	Light
Protrusion decreased	$1\,1/8$	130	68	77
	$1\,3/16$	138	65	84
	$1\,1/4$	143	65	94
	*$1\,5/16$	148	67	100
Protrusion increased	$1\,3/8$	162	64	104
	$1\,7/16$	167	62	95
	$1\,1/2$	177	59	77

* This is normal operation.

Under conditions of low current resulting from low line voltage, the negative carbon will burn with a blunt point and the arc will tend to wander and become unstable.

In the case of high current caused by high line voltage, the negative carbon will tend to spindle and the arc will flicker from overload.

Cases have been noted where negative carbons were burning with blunt points in some lamps and were spindling in other lamps on the same set because of conditions of extreme unbalance on the 3-wire set load.

It is to be noted that the variations mentioned show up only under conditions of extreme change. The automatic features of the lamps will compensate for slight variations and the lamp operator is able to control the current to some extent with manual adjustment. Nevertheless, the variation in light output and steadiness of light indicate that close line-voltage control will result in vastly improved operation.

EFFECTS OF VARYING LINE VOLTAGES ON INCANDESCENT LAMPS

Table 4 shows that an extreme case of drop from a normal "on-set" voltage of 115 to 100 v would result in a light loss to 62 per cent of normal. While an increase from 115 to 120 v would cause a gain to 116 per cent of the light, such an extreme change would result in obtaining only 57 per cent of expected life. The foregoing is based on lamps with rated voltage of 115 v.

TABLE 4

Variation of Light, Life, and Wattage of Gas-filled Incandescent Lamps When Operated at Voltages Above or below Their Rated Voltage

Voltage Delivered at Socket	Per Cent Light	Approximate Per Cent Life	Per Cent Watts	Voltage Delivered at Socket	Per Cent Light	Approximate Per Cent Life	Per Cent Watts
For 120-V Lamps							
100	54	1090	76	111	77	280	89
101	56	956	77	112	79	250	90
102	58	840	78	113	82	220	91
103	60	740	79	114	84	195	92
104	62	650	80	115	87	175	94
105	64	570	82	116	89	155	95
106	66	505	83	117	92	140	96
107	68	450	84	118	95	125	97
108	70	400	85	119	97	110	99
109	72	350	86	120	100	100	100
110	75	310	88				
For 115-V Lamps							
100	62	625	81	111	89	160	95
101	65	550	82	112	91	140	96
102	67	480	83	113	94	125	97
103	69	425	84	114	97	110	99
104	71	375	86	115	100	100	100
105	74	330	87	116	103	89	101
106	76	290	88	117	106	90	103
107	78	260	90	118	109	72	104
108	81	230	91	119	112	64	106
109	83	205	92	120	116	57	107
110	86	180	93				

EFFECTS OF VARYING LINE VOLTAGES ON COLOR

Because of changes in color temperature with voltage changes on both carbon arcs and incandescent lamps, the demands for proper voltage regulation on color sets are greater than on black and white. Even so, it is possible to tolerate greater differences in a 3-strip system such as used by Technicolor than with a monopack system where the

prints are also made on a monopack film. If and when this latter printing system comes into studio use, the demands for color temperature control will increase, and with it the further need for close set voltage control.

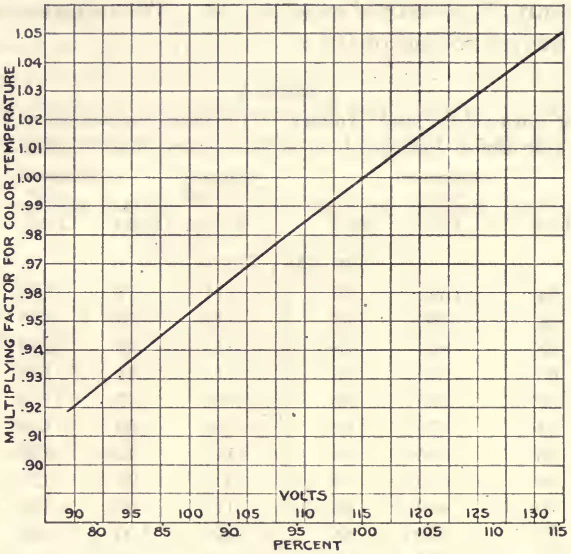

FIG. 10. Variation of color temperature with change of voltage. 100- to 130-v types incandescent lamps.

Fig. 10 shows variation in color temperature with voltage for incandescent lamps. The question of color temperature change with voltage for carbon arcs has been previously covered.[1]

CONCLUSION

Close voltage control on motion picture sets results in economy of operation, greater lamp efficiency, and less manual adjustments of carbon-arc units. Where the studios are equipped with adequate wiring and where 3-wire balance is maintained by "on-set" voltmeters, the entire problem of set lighting is greatly simplified.

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REFERENCE

[1] BOWDITCH, F. T., AND DOWNES, A. C.: "Spectral Distributions and Color Temperatures of the Radiant Energy from Carbon Arcs Used in the Motion Picture Industry," *J. Soc. Mot. Pict. Eng.*, **XXX,** 4 (Apr. 1938), p. 400.

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CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

28, 7 (July 1947)

Historical Development of Sound Films Pt. 1 (p. 235)
E. I. Sponable

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New Technical Developments (p. xix) R. H. Cricks

Colour: Future Problems (p. xxxi)
T. T. Baker

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# JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

Vol 49 OCTOBER 1947 No. 4

AMERICAN FILMS ABROAD*

ORTON H. HICKS**

Summary.—*This paper describes the importance of the distribution of American films overseas to the motion picture industry, to the national economy, and to the cause of world peace.*

Overseas markets for American films are of vital importance to you as motion picture engineers and executives. Naturally you have been interested in these overseas markets and overseas films for many years, and you were especially interested in them during the war when you played such a large role in bringing high standard equipment and films to the Armed Services.

It was my job to distribute those films, especially the 16-mm entertainment gift prints. These were donated by the industry to the Army and Navy. There have been some very interesting after-effects resulting from those gift prints.

By acquiring the motion picture habit, the returned veterans have learned to demand *better* pictures and *more* pictures. Their critical sense has been increased. For instance, we are now able to book to the small towns throughout the country good pictures on the week ends. Previously these towns played the horse-opera type of movie.

So far as more pictures are concerned, there was a little item in the New York *Times* that read as follows:

"Lewes, Delaware—Tomorrow night will mark the end of another 'blue law' of this 315-year-old town. Sunday movies will be shown for the first time, and if the shades of the Holland Dutch founding fathers who landed here in 1631 hover in disapproval over the town's one movie theater, no one will be surprised. Their observance of the Sabbath was strict enough to have lasted more than three centuries.

* Presented Apr. 21, 1947, at the SMPE Convention in Chicago.

** Loew's International Corporation, New York, N. Y.

"Returning service men expressed a desire for a referendum early this fall. When the vote was conducted a fortnight ago an overwhelming majority approved."

There has been another advantage that we found overseas. Those gift prints, although intended only for the Army and Navy, were shown to the local inhabitants wherever we happened to have troops with the result that the motion picture habit has been inculcated in them. Film companies find that the 16-mm program is progressing rapidly in the Far East, the Middle East, West Africa, wherever we had troops; whereas in South America, where we did not have troops, the demand is not so great.

On the debit side we find that many of these prints have been stolen, or let us say "borrowed". There is great difficulty in impressing upon the layman the sanctity of a copyright. That was brought home to us very vividly not long ago when we received a letter from an Army major stationed at a local air base. He told about the great pleasure that his family and friends had had as a result of bringing back from Iceland a print of "For Me and My Girl" with Judy Garland. He had now been ordered to Alaska and he did not want to take a print to Alaska that was not in the best condition. He asked if we would replace it with a new print if he sent it back. He got the answer and we got the print.

Another repercussion has been in the very human failing of not wanting to pay money for things that have previously been given free. An incident in that connection happened out in the Philippines at a little town called Los Banos, about a hundred miles from Manila. The first night that we tried to show pictures there a number of armed bandits shot up the lobby of the theater. The exhibitor refused to run the show but was forced at the point of a gun to continue. After the show the bandits retreated to the hills—they did not rob anyone. They resented the fact that anybody should be charged for motion pictures after three years of free shows that the Army had been giving them!

My present assignment is to apply to the distribution of entertainment films the same methods we learned in the Army and Navy. Commercially, like all corporations, we answer to a board of directors, but culturally we answer to the world. Mr. Arthur Loew, in our Basic Manual, has stated his beliefs as follows:

"What makes this world-wide distribution so significant is the fact that films are the nearest thing yet perfected to a universal

language, with undeniable cultural, political, and social force. Films are able to convey ideas to more people more intelligibly, accurately, and graphically than any other medium of communication.

"To illustrate this point, it can be said that most persons, thanks to motion pictures, have mental pictures of far-off places and things they actually have never seen. Industrial workers who have never left the city know much about the farmer, and vice versa, because of entertainment films. 'Mrs. Miniver' taught the world more about the spirit of England and the temper of its people than all the text-books put together.

"In this peace-seeking aftermath of war, the most distressingly elusive commodity is simple understanding among nations, and it is precisely this commodity that motion pictures are able, in and of themselves, to impart.

"This is why it is our responsibility and that of the industry to make motion pictures available everywhere. And this is why freedom of the screen must be our guiding principle."

We have found two barriers in reaching that goal. The first barrier is economic and the second barrier is cultural. We are removing the economic barrier by introducing 16-mm operations into these remote corners of the world where 35-mm could not operate profitably. This is not only because of the mobility and economy of 16-mm equipment, but also because of the cost of transporting the films. In some instances overseas more has been paid for 35-mm film transportation than was received on the royalty for the picture itself. We are removing the cultural barriers in two ways. The farther away from the centers of civilization the greater the illiteracy, and, therefore, superimposed titles at the bottom of the screen are not of any real value because the people cannot read. We have overcome that by dubbing the native language onto the film itself.

The other method is a new one and is less expensive. It is called narration. The sound track is tuned down at certain intervals and a voice in the native language comes on and explains the action and gives other information that will make the picture more enjoyable. We are doing narration in five languages, Portuguese, Arabic, Hindustani, Chinese, and Siamese. Complete lip synchronization is done in Spanish, French, Italian, and, before the war, German. As a consequence many more hundreds of thousands of people are going to become motion picture devotees and will be drawn into the world circle of neighbors.

You cannot put on a program like this without trained personnel. At the end of the war each of our overseas offices selected some young national of the country involved and he was sent to the United States for training. There were ordinary routine matters such as spending days in our exchanges and nights in our theaters, a couple of weeks at the studios, and a few weeks at projector factories. In addition, we tried to give them some extracurricular activities. For instance, we sent them to Washington for a week to their own embassies and to meet the people in the United States Government who are interested in motion pictures. We sent them to the University of Chicago to see the *Encyclopedia Britannica* films in order to acquire some feeling toward educational films. We usually had them travel by day train because we wanted them to see the country. Then they came to New York for the final summing up. We had an editorial writer from the New York *Times* meet with them evenings and answer their questions about the United States.

These men have gone back to their own countries. What are we doing now to give them ammunition? For one thing we are sending the best possible pictures. We think Hollywood makes good pictures, and we try to send the best ones, eliminating those that may give an unfavorable reaction toward the United States. Of course, the best way to remove the possibility of such a reaction is to nip it at the very source by not making pictures that will give an unfavorable reaction. For that purpose we have created an International Information Center, and it is the duty of that organization to revise scripts, to make suggestions that will make pictures more presentable overseas, and to eliminate these disquieting influences that we have had occasionally in the past.

In selecting pictures there is a fine line to be drawn that requires nicety of judgment. Sometimes we lean over backwards, I am afraid. You may have seen this item in one of the papers about "The Grapes of Wrath". "Oslo—Municipal authorities today forbade a showing here of the motion picture, 'The Grapes of Wrath,' because American distributors insisted that audiences be told the conditions depicted are not normal in the United States." Subsequently we withdrew our insistence and the film was shown without any foreword.

There are other pictures such as "Mr. Smith Goes to Washington", a picture that we could send to Great Britain because there the democratic process is understood. However it is a film that we could not and would not send to many other countries.

One final thing that we do in the way of providing ammunition is through an arrangement with the State Department. Sixteen-millimeter prints are prepared in the English language and sent to our embassies through the courier service of the State Department. That enables our ambassador to invite the leading politicians and officials of each country to see our latest pictures. So far that service is operating on a weekly basis only in Russia.

In a letter from Ambassador Smith, he describes the great value that has resulted from showing these pictures to a small select group of Russian officials and he believes the results to be of great benefit to the American people and to American industry.

I can tell about Russia in ten seconds because I know only three things: (1) They have 17,000 theaters, practically the same number that we have. (2) Deanna Durbin is the most popular American actress. (3) Within recent years we have sold only three American pictures to Russia and for those three we have received a total of $25,000 which happens to be the same amount that those pictures earned in the city of Prague alone. You may well say that we should give our pictures to Russia. Maybe the industry would if we could be sure that they would be shown. However, let me reassure you that in no case has Russia been denied any picture because of price. We have always been able to agree on a price that Russia is willing to pay.

Any pictures sold to Russia in the future will be sold through the Motion Picture Export Association. That is a corporation formed under the Webb-Pomerene Act to distribute American pictures in those countries where a monopoly exists and where it is impossible to engage in free trade. There are thirteen countries thus served: Holland, Germany, Poland, Austria, Hungary, Czechoslovakia, Rumania, Yugoslavia, Bulgaria, Russia, Japan, Korea, and the Netherland East Indies.

The Motion Picture Export Association is owned by the eight major companies. No regard is given to the selection from any one individual company. In other words, the selection is made from those pictures which we think will do America the most good. Naturally we try to obtain a balance in that—a certain number of dramas, musicals, comedies, and other pictures—and we are careful to try to introduce new American stars because they have a great box-office value overseas just as in this country.

Newsreels are distributed in native languages in every country that will permit us to distribute newsreels.

The reaction to our pictures is what you might expect. The people are tired of war pictures, they want escape. In a theater in Budapest the picture "Casablanca" was being shown. You may recall that in that film the Germans start singing "Watch on the Rhine" and they are drowned out by the French populace singing "La Marseillaise". The audience in Budapest became so imbued with this spirit that they joined the French chorus and kept on singing through the next two reels. Finally they forced the operator to rethread and run the reel over again.

The theaters overseas need new equipment, new seating arrangements, and better sanitary facilities. We need new theaters everywhere. The standards of exhibition in many countries overseas are not what we have here. One of the worst examples we came across was in a town in Gambia. The theater has one 16-mm projector, and the operator is afraid of overheating. Accordingly, he charges full admission for running one 1600-foot reel, then stops the picture and says, "If you want to see the rest you can come back tomorrow night at the same admission."

In a little town about 60 miles from Bogota, Colombia, we had an exhibitor who was paying a flat rental and we wanted to check on him. We drove out there one night about six o'clock. We couldn't see any evidence of a theater. The town was about a block long and had a population of about 500 people. We drove up and down and we saw some people going into a private home. We followed them and inside of the home there was a man collecting money. He had torn down the back of his home and built a barn and that was the theater. There were only about 30 people, and he was charging them the equivalent of $1.16 apiece. That is a higher price than we get in our first-run theater in Bogota. After the show we asked him why he was charging such a high admission and why he wasn't advertising. He said, "I want to keep out the riffraff." Inasmuch as he was paying a flat rental we couldn't argue too much, but it is our goal to try to bring to these remote 16-mm theaters overseas the same standard of exhibition that we have in this country.

As for the number of theaters overseas—according to the Department of Commerce's latest count there are 83,668 theaters and only about 20 per cent of those theaters are in the United States. In other words, four out of five theaters are overseas. That gives you some idea of the importance of our overseas market. It is important for three reasons. It is important to the motion picture industry,

it is important to the national economy, and it is important to the national security.

It is important to the motion picture industry because if we lose that 40 per cent of our income or any part of it, we are going to have to raise admission prices in this country, or lower the quality of our pictures, or decrease the number of personnel working in the industry and decrease the amount of money that is paid for research and other activities.

The overseas market is important to the national economy. As you know, motion pictures—whether American, British, French, or Spanish—have done more than any other medium to raise the standard of living of civilized peoples throughout the world. More washing machines, more radios, more automobiles, have been sold indirectly by motion pictures than by any other form of sales enterprise or promotion.

The overseas market is important to the national security because motion pictures are helping to win the peace. On that subject let me read what Eric Johnston recently said: "The free exchange of ideas is even more important than the free exchange of goods. There cannot be one world as long as there are any 'foreigners' in it. The meaning of the word 'foreign' must disappear, and with it the plurality of discordant foreign policies by which the nations are divided. The people of the world will cease to seem strange to one another only when they know each other as neighbors do. To bring them to such knowledge of one another is a mission which the motion picture is peculiarly fitted to perform."

It would be oversimplification, of course, to maintain that freedom of the screen alone can bring enduring peace. But it would be equally naïve to believe that enduring peace can be obtained without freedom of the screen. A free screen can bring about world understanding and world education.

It was H. G. Wells who said, "Civilization is a race between education and disaster." Motion pictures will play a vital role in winning that race!

DISCUSSION

MR. N. D. GOLDEN: In the short space of time that Loew's International has been operating the 16-mm program abroad, approximately how many theaters are there in the foreign market?

MR. ORTON H. HICKS: I wish I could answer that, but I do not have the figures here. We break it down according to countries. In some countries where

there was already a large 16-mm operation the business has been phenomenal. In France there are something like four thousand 35-mm theaters and about nine thousand 16-mm locations. Most of those are served by mobile units. I think there are something like 1900 mobile units covering France. In some of our branches in France we are making more 16-mm shipments than we are 35-mm shipments. In England there are several hundred. I don't know the exact number. If we had to figure out the whole world, I would say that France at this stage of the game is probably as big as the rest of the world combined, because elsewhere it is in the pioneering stage and it is not in France.

MR. GOLDEN: Has not the retarding factor been your inability to secure sufficient 16-mm equipment to carry out your program?

MR. HICKS: That has held it up somewhat, but I should be making an alibi if I tried to pretend that we could go ahead much more rapidly merely because of equipment. The projector manufacturers have been wonderfully co-operative and very farsighted in realizing that this foreign market is important. They have made much fairer allocations to the foreign market than many other industries have made.

It would be helpful in some of these countries if we did not have the dollar problem. In Chile it is pretty difficult to persuade anyone to import equipment because you have to have a license and you have to pay in American dollars, and how are you going to get those American dollars out of the country? That is holding us up in many places. As a rule, I think that we are over the equipment hurdle and I know of no place where we are seriously handicapped by lack of equipment. I am wrong, there are some places where the countries insist on not importing any equipment whatsoever. They manufacture their own. That is true of Great Britain, Australia, and Italy. Italy and Great Britain will continue to be a big problem because they are shipping so much of their manufactured goods overseas in an attempt to create dollar exchange.

MR. WILLIAM KRUSE: In regard to censorship, Louis de Rochemont gave a slightly opposite viewpoint as to whether it is the business of the motion picture industry to apply censorship or flattery to the films we send abroad. Remember, the British let us see "Henry VIII" without polishing up his table manners. Is it really the business of the industry to clean them up before we send them to the audiences of Europe?

MR. HICKS: I certainly am not qualified to act as spokesman for the industry on that subject. Just let me give you my personal opinion. I do not think we have any business doing that in a country such as Great Britain or Norway. An interesting aftermath of the little article I read you about "The Grapes of Wrath" was that the Norwegians refused to let the picture be seen with the title explaining that the conditions were not typical of the United States, that they arose because of certain economic conditions that prevailed for awhile, and that they were corrected when called to the attention of the authorities. The Norwegians said, "We were a free people long before you. We think we are qualified to discern the difference between truth and misinformation. If you want to show the picture, let us form our own conclusions." I think they are right. On the other hand, there are many countries where the showing of "Mr. Smith Goes to Washington", would do us harm. The democratic process has been misrepresented in some countries and a picture such as this would do more harm than good.

We had an interesting thing happen in connection with "The Grapes of Wrath". In Yugoslavia there was a picture being shown called "American Paradise". We checked the records and no such picture had ever been made in the United States; furthermore we were not doing business with Yugoslavia at the moment. At last the State Department discovered what was happening. They sent one of their representatives and he found the theater where this particular picture was playing. It opened with the title, "American Paradise", and it had the regular credit lines and then it broke into the picture. The picture was "The Grapes of Wrath".

I think a picture shown under that title in Yugoslavia can do us harm.

MR. GOLDEN: May I be permitted to say a word in connection with Mr. Kruse's comments? I am not going to defend the industry but I do think that the American motion picture industry can use good discretion in the selection of the types of films that we send abroad. There are many countries abroad that would like to select a particular type of picture that would not show the American way of life in the best manner. They would want it for the purpose of propaganda. Russia would like to select just those pictures that fit its ideology and pictures that would show the Russian people the worse things of American life. No one particular picture that is produced can show the whole drama of American life, but if you take a cross section of most of the pictures produced, you will have a good, clear understanding of the American way of life. Unfortunately, some countries have set up barriers against the showing of American pictures because they are fearful that we may turn over to their people our ideas and our ideals. They don't want those, they just want to pick and select certain types of pictures.

Many reports come across my desk and they show that some foreign governments that have an ideology contrary to ours would like to have the right of selection. That is the reason why Mr. Hicks told you that Russia has picked only three pictures in recent years and purchased them from our country. They do not want to show our American way of life. The American picture has always been one of the most saleable products in foreign markets. It was also the greatest medium through which we sold America to the foreign countries. That is why it was the first commodity to be barred in foreign countries such as Italy and Germany long before we ever got into the war.

DR. E. W. KELLOGG: Since your organization pays for itself and is not entirely altruistic in its operation, how do you carry out the policy fostering the distribution abroad of films that will do us the most good in the sense of promoting international good will?

MR. HICKS: I presume that you are referring to the Motion Picture Export Association which operates in the thirteen countries I mentioned. The way that the corporation is set up is that the eight major companies own part interest in it. The interest owned is in direct relation to our normal percentage of business around the world. That is the same basis upon which the major producers have always supported the Hayes Office, and now the Johnston Office. If, for instance, Metro's share of the world business were 22 per cent, we would pay 22 per cent of the bills of the corporation and we would take 22 per cent of the income. Under those circumstances, it doesn't make any difference to MGM whether we have any pictures in there or not. The directors of the Motion Picture Export Association are entirely free to choose those pictures which they think will best depict America

abroad, although they invariably consult with the Committee on Selectivity of M.P.A.'s International Division.

MR. KRUSE: The point that Mr. Golden made about countries wanting to buy pictures attacking our way of life would have been good if it was not for the fact that the pictures which Russia picked were Deanna Durbin's. If you can find anything critical of the American way of life in that type of picture, I would like to see it.

Do you not think you are mixing up propaganda and entertainment? For every entertainment picture that is made that is critical there are a hundred made that are not critical. Mr. Hicks pointed out that the Norwegians certainly resented this censorship.

When the picture "Boomerang" was shown in Britain, every single critic praised the film because at last the Americans were getting grown up enough to give them pictures that were not made up of milk toast and honey.

MR. HICKS: Let me say, Mr. Kruse, that I think you are reading into this a censorship which does not exist as viciously as you imply. There are about 1200 films in our backlog—pictures that were not released in those countries during the war. Is it not to the industry's interest as well as to America's interest to pick the best of those 1200 in view of the fact that we can only distribute 52 to 104 pictures a year? I think we should pick the best pictures.

THE PROCESSING OF TWO-COLOR PRINTS BY DEEP-TANK METHODS*

JOHN G. STOTT**

Summary.—*In the commercial production of two-color prints on duplitized positive film printed from bipack negatives, usual processing methods involve one or more flotation or mechanical application operations in order to prevent the treatment of the image on one side of the film with the color intended for the opposite side. These operations may be slow, difficult to control, and involve considerable waste. A method is outlined whereby a protective coating is applied to one side of the film so that the opposite side may be treated by total immersion to form the proper color for the unprotected image. The coating is then removed, and the previously protected side of the film is treated. The entire process may be done in conventional processing machines by total immersion of the film in the processing solutions.*

During the past two years considerable interest has been revived in the production of two-color prints for general 35-mm theater release. This has been a result of mounting theatergoer demand for

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motion pictures in color and the immediate lack of sufficient production capacity in three-color motion pictures to satisfy this demand. In addition, the production of two-color pictures is a relatively simple process as compared to three-color processes. This is especially true at the camera stage of the process since bipack negatives may be exposed in conventional black-and-white cameras with only minor modifications.[1] The printing of duplitized film from bipack negatives presents several problems not usually encountered in black-and-white printing since registration of the two images on opposite sides of the film is of prime importance, but this difficulty has been successfully worked out in several types of step printers. This paper is not concerned with these problems but rather with the problems involved in processing the exposed duplitized film so that the proper color is applied to the proper image.

A typical scheme for processing the exposed duplitized positive film in order to produce a two-color print is shown in the following outline:

Process Step	Image
Black-and-White Processing	
(*a*) Develop in black-and-white developer (*b*) Stop and fix in hypo (*c*) Wash	Silver on both sides of film
Dye-Mordanting	
(*a*) Treat one side of film in iodizing solution (*b*) Clear in bisulfite solution (*c*) Wash (*d*) Dye silver-iodide image (*e*) Wash or backwash in acid	Dyed silver iodide on one side of film and silver on other side
Prussian-Blue Toning	
(*a*) Immerse film in Prussian-blue toning solution	Dyed silver iodide on one side of film and Prussian blue on other side
Finishing	
(*a*) Wash (*b*) Fix and harden (*c*) Wash (*d*) Dry	Silver iodide removed as well as silver ferrocyanide in Prussian-blue image making images transparent

As outlined above the first three steps may be done in a conventional black-and-white processing machine with undercut film spools.

In the entire process the only stage that need be dark is the black-and-white development and sufficient treatment in the hypo or stop bath to arrest development.

Numerous papers have been published and many patents granted which describe methods of converting a silver image on only one side of duplitized film to silver iodide. Various methods for applying a solution to only one side of the duplitized film have been described by Kelley,[2] Brewster,[3] Capstaff,[4] Mason,[5] Troland, Ball, and Andrews,[6] and others. Miller[7] and Cory[8] have described methods of converting a silver image in a photographic film to silver iodide suitable for mordanting a basic dye.

These mechanical methods of iodizing one side of duplitized film are effective when properly handled, but considerable care must be exercised to prevent print damage from accidental treatment of the opposite side of the film. In some cases these methods may require slow film movement throughout the process and thus seriously limit production capacity for a given plant area.

Therefore, at this stage of the process one side of the duplitized film has been suitably prepared such that by immersion in a basic dye solution the silver iodide will function as a mordant to cause deposition of the dye in proportion to the density of the original silver image. Before this treatment, however, it is necessary to remove the excess iodine left in the film as a result of the iodizing treatment. This has been described by Wall[9] and involves treating the film in a dilute solution of sodium bisulfite.

After a wash to remove reaction products from the previous treatments, the film is immersed in a solution of basic dye. This dye will mordant only to the silver-iodide image without affecting the silver image on the opposite side of the film. Thus this operation may be done by total immersion of the film in the dye solution. Choice of various dye mixtures or single dyes as a satisfactory colorant for the print made from the bipack orthochromatic negative depends on many factors beyond the province of this paper.

The film is then washed thoroughly in water to remove the excess dye in the gelatine of the film. Miller[7] and Cory[8] have described methods of backwashing the film with solutions of weak acids to hasten the removal of excess dye and give stain-free high lights in the final print.

Crabtree and Matthews[10] have published a toning formula which will convert a silver image to a Prussian-blue image. The film may

be immersed in the toning solution since the treatment has little effect on the previously applied dye-mordanted image on the opposite side of the film. Therefore, the film at this stage of the process consists of an orange-red dye-mordanted image on one side of the film and a Prussian-blue image on the opposite side of the film.

After suitable washing, the film may be fixed and hardened as described by Miller[7] and Cory[8] in order to render the images more transparent and suitable for projection. Final washing and drying complete the process.

In recent years, several processes have been patented which are designed to improve the transparency and definition of the dye-mordanted and toned images, extend the uses of duplitized film to three-color processes, and improve the color rendition of two-color processes by the better choice of colorants for the two records. In general the chemistry of these improvements will not alter the basic requirements for the process herein outlined.

It can be seen that the processing of duplitized film to yield two-color pictures could be made a relatively rapid and easily controlled system if some method could be devised to eliminate the flotation or mechanical application step and treat the film in conventional deep-tank processing machines. This has been done by applying to one side of the duplitized film a protective coating which is impervious to the treating solutions and which can be removed easily without altering the characteristics of the treatment applied to the unprotected side of the film. The idea of using "resists" for various types of photographic processing is not new having been described by many inventors including Kelley,[2] Shorrocks,[11] Mannes and Godowsky,[12] and Lierg.[13] Using a protective coating which is impervious to an iodizing solution, the following scheme could be used to process duplitized film by total immersion of the film in the processing solutions at every stage of the process.

It can be seen that the rate of film movement through the process is limited only by the usual limitations of a continuous processing machine with a multiplicity of tanks. Control of the iodizing step is simplified since the solution may be vigorously agitated with no danger of accidental treatment of the opposite side of the film.

The key to this process is the protective coating applied to one side of the duplitized film. Several types of protective coatings were considered. Tests were made on materials removable from the film by treatment in solutions of strong acids. It is evident that

selection of such a material for this specific purpose would be difficult since the iodizing solution functions most effectively when acid. It was decided that this type of protective coating was not practicable for this type of process.

Process Step	Image
Black-and-White Processing	
(*a*) Develop in black-and-white developer (*b*) Stop and fix in hypo (*c*) Wash (*d*) Dry (*e*) Apply protective coating to one side of film (*f*) Dry	Silver on both sides of film
Dye-Mordanting	
(*a*) Iodize in deep tank (*b*) Clear in bisulfite solution (*c*) Remove protective coating (*d*) Wash (*e*) Dye silver-iodide image (*f*) Wash or backwash in acid	Dyed silver iodide on one side of film and protected silver image on opposite side
Prussian-Blue Toning	
(*a*) Immerse film in Prussian-blue toning solution	Dyed silver iodide on one side of film and Prussian-blue image on opposite side
Finishing	
(*a*) Wash (*b*) Fix and harden (*c*) Wash (*d*) Dry	Silver iodide removed as well as silver ferrocyanide in Prussian-blue image making final images transparent

Attention was then turned to protective coatings that are soluble in alkaline solution. If such a material could be found that would exclude the iodizing solution from the emulsion of the protected side of the film, the system should be simple to control since, as mentioned before, the iodizing solution functions most effectively when acid. Thus the coating would remain intact throughout the iodizing treatment and be removable in an alkaline solution which would not affect the iodized image.

One alkali-soluble coating material which is familiar to the motion picture industry is Eastman Universal Protective Film Lacquer.

This product was originally described by Talbot[14] in connection with the protection of finished prints from scratching, abrasion, and oil-mottling during projection. In designing this product it was known that it is difficult if not impossible to prevent abrasion and scratching of projected prints with any type of protective coating. Therefore, it was reasoned that with a protective coating on the film, the majority of the scratches and abrasions suffered during projection would be confined to the thickness of the coating. The lacquer

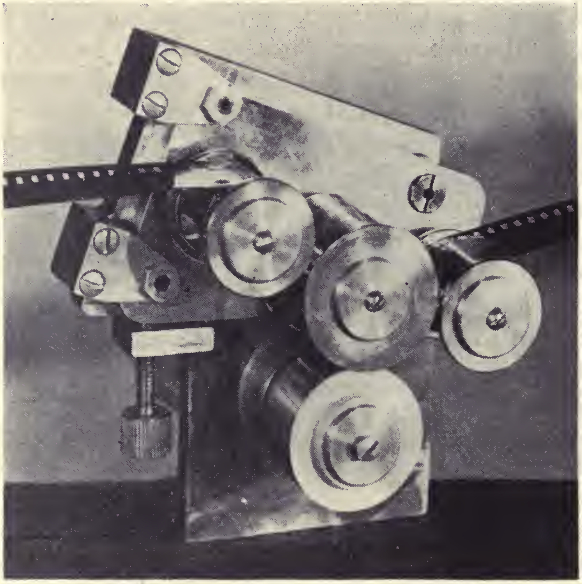

FIG. 1. Apparatus for "bead" application of lacquer to film.

was so formulated that when the coated film is treated in a dilute solution of sodium carbonate or in a standard positive developer followed by a short water wash, the lacquer is removed without buffing or scrubbing. Thus the scratches and abrasions will disappear with the lacquer.

Tests were made on this lacquer. These original tests were remarkably successful although it was immediately learned that a somewhat different lacquer formula was required. It was also learned that a heavier coating than ordinarily is necessary for print protection during projection was advisable. The most satisfactory

results are obtained when the lacquer is "bead-applied" since this gives greater control of the coating thickness over a wide range of machine speeds. Whereas a coating thickness of about 0.0001 inch is usually satisfactory for adequate mechanical print protection, it is advisable to have a coating thickness of about 0.0002 inch for chemical protection of one side of the film during this type of processing. Using this lacquer spread more than 10,000 feet of 35-mm film may be coated on one side with one gallon of lacquer.

The lacquer must be applied to dry film. Therefore, the bead applicator may be installed in the drying cabinet of the black-and-white stage of the process such that several drying loops are available after the application of the lacquer to dry the coating properly.

Fig. 1 shows a bead-application device which has been used successfully in this type of work. In this device, as the film passes over an idler roller, lacquer is applied at the bottom surface from a second applicator roller spaced just out of contact with the film. This applicator roller is slowly driven and carries the lacquer up from a pan (not shown) and applies it to the film through a liquid bead maintained by the surface tension of the lacquer.

Studies were made on how much undercutting could be expected at the edge of the lacquer coating by the iodizing treatment. It is interesting to note that for the iodizing treatments used in these studies this undercutting did not exceed 0.001 inch. However, this figure will vary depending upon the time of the treatments and the iodizing solution used.

In "bead-application" of a lacquer, the coating cannot be applied over the entire area of the film since the lacquer will wet through the perforations and cause transfer on the opposite side of the film due to wetting of the rollers of the application device. In practice, it has been found that the lacquer coating may be bead-applied well into the perforation area without causing leakage of the lacquer through the perforations and thus transfer on the opposite side of the film. This wider coating provides a margin of safety several times greater than the amount of undercutting to be expected, and thus insures against contamination in the sound track or picture area due to this effect.

Fig. 2 illustrates the above point. Here a length of Eastman 35-mm Duplitized Positive Film has been flash-exposed across the entire film area on only one side of the film. This film was then processed to form a black-and-white image, lacquer-coated using the bead

method, and then iodized, cleared, fixed, washed, and dried. Thus the black pattern within the clear perforation area represents the area of the film protected by the lacquer coating. It is apparent that any slight undercutting of the lacquer coating occurring here will not affect either the picture or sound track.

It was found in studying this process that careful application of the lacquer to the film eliminates many difficulties in the subsequent processing. Some of the early tests revealed minute pinholes in the coating which caused contamination of the protected side of the film with tiny specks of the wrong color. It was learned that these were

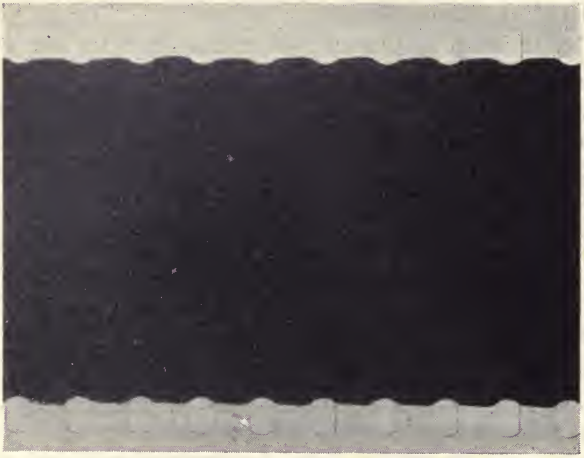

FIG. 2. Darkened portion of film indicates area to which lacquer is applied by bead applicator.

caused by minute particles of dirt that had deposited on the film either during wet processing, drying, or handling. Careful filtering of the processing solutions, and the air used in drying the film, and care in handling eliminated this difficulty.

For various reasons it may be desirable to alter the order of treatment in making two-color prints. Since the protective coating is also impervious to the Prussian-blue toning solution, the image printed from the ortho negative may be protected with the lacquer coating and the Prussian-blue tone applied to the unprotected pan negative print first. Should this be done, a minor complication arises. The subsequent treatment in alkaline solution to remove the lacquer will render the Prussian-blue image brown. This is caused

by the fact that Prussian blue (ferric ferrocyanide) is converted by alkali to ferric hydroxide which has a characteristic brown color. Ferric hydroxide is quite insoluble in alkaline solution so the image does not dissolve completely but redeposits in the film. Thus after the alkaline treatment to remove the lacquer, the brown image may be converted to the original Prussian-blue image by treatment in an acid solution of ferrocyanide. Inversion of the process in this fashion thus adds one more chemical processing step and one more wash. It is also possible to work out other processes such that the red image is formed by toning and the blue image by dye-mordanting. Likewise both images may be formed by dye-mordanting by the use of two "resists" at various stages of the process. This procedure may be desirable in order to provide better colorants for the two records and thus improve final screen results.

This type of alkali soluble "resist" may be used for these processes only when the protective treating solution is acid. It has been found that this lacquer coating when properly applied will provide adequate protection to the coated emulsion as long as the treating solution has a pH less than 3.5. However, where it is possible to choose between a dilute treating solution and a longer treating time and a more concentrated solution and a shorter treating time, in most cases it would be advisable to choose the latter procedure in order to minimize the possibility of penetration or deterioration of the coating even in the acid solution. These details would have to be worked out for the particular process being developed.

The lacquer coating is removed by immersion of the film in a 2 per cent solution of sodium carbonate for two minutes followed by a two-minute wash in running water. Although the lacquer does not dissolve completely in the removal solution but tends to loosen and slip off the film, the removal solution may be replenished in the usual manner as long as the rate of replenishment is high enough to prevent sludge accumulation.

No attempt has been made to produce any length of two-color film suitable for projection using this process. All of the work has been done on a small scale, and most of the studies have been made on the investigation of the protective aspects of the lacquer coating only. The chemistry of this type of process is in general straightforward and is covered thoroughly in the literature. Although it is appreciated that testing of this protective lacquer for this use has not been extended to actual machine processing, it is felt that these studies have

indicated that the product will function satisfactorily in practice for the purpose herein outlined.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Mr. R. H. Talbot for many helpful suggestions and his work in compounding the new lacquer and preparing the film samples on which these studies were made.

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DISCUSSION

CHAIRMAN FILLMORE: Is this process in use commercially or is it just in the laboratory stages at this moment?

MR. J. G. STOTT: It has not been commercially applied.

CHAIRMAN FILLMORE: Will it be commercially available in a short time?

MR. STOTT: The lacquer is available immediately. The chief thing that is required is to set up a bead-application device in the drying cabinet of the black-and-white stage of the processing machine. Adjustment should be made such that the coating thickness is sufficient.

MEMBER: What is the name of the lacquer?

MR. STOTT: Eastman Protective Film Lacquer.

CHAIRMAN FILLMORE: What is the iodizing solution?

MR. STOTT: There are a large variety of iodizing solutions. One type is a solution of potassium iodate, potassium iodide, and acetic acid.

CURRENT BLACK-AND-WHITE DUPLICATING TECHNIQUES USED IN HOLLYWOOD*

NORWOOD L. SIMMONS AND EMERY HUSE**

Summary.—*The duplicating process has been studied at five Hollywood laboratories. Prints made both by the duplicating process and directly from an original negative have been obtained from all five laboratories. No attempt was made in this study to include the sound track.*

A complete sensitometric study was made using both the printed-through technique and customary Type IIb Sensitometer gamma controls for each step in the duplicating process. Resolving-power measurements throughout the various steps in the process were also obtained.

Considerable variation has been found in the degree of fidelity of the duplicating procedure at the five laboratories studied. In most instances it is possible to determine the cause or causes of poor quality by examination of the sensitometric data. Underexposure of either the master positive or the duplicate negative or both is found to be the greatest cause of lack of proper tone reproduction in the duplicate prints.

INTRODUCTION

Since the inception of fine-grain duplicating films in 1936[1] very little has been written about the motion picture duplicating process. The use of duplicating films has increased disproportionately in comparison with the use of motion picture films in general. Composite duplicate negatives or master positives are sent abroad for foreign release printing. In many instances the final edited negative for domestic release printing consists of 50 per cent or more duplicate negative. When such a release negative is duplicated *in toto* in order to provide foreign release negatives, a corresponding portion of the latter becomes a second-generation duplicate.

For all subject matter requiring the use of an optical printer, duplicating becomes a necessity. The optical printing technique has acquired great significance. It is used for making lap dissolves, wipes, blowups of a portion of the original scene, straightening an exposure which was originally shot with a tilted camera, and so on.

Less frequently the duplicating process has been utilized to correct mistakes made in the exposure or development of the original negative. An overexposed negative, which prints outside the normal

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* Presented Apr. 22, 1947, at the SMPE Convention in Chicago.

** Eastman Kodak Company, Motion Picture Film Department, West Coast Division, Hollywood, Calif.

printing light scale, may be brought down to a reasonable printing light level by making a duplicate negative. Errors in contrast of the original negative may be easily corrected by adjusting the development of a duplicate negative. It is not possible, of course, to correct for too great a degree of underexposure in the original negative by making a duplicate negative. However, if an original negative is somewhat underexposed and suffers from low contrast because of this underexposure, this condition may be palliated somewhat by making a correctly exposed duplicate negative at higher than normal contrast.

In order to determine the degree of fidelity in reproduction of the picture negative by the duplicating process, periodic survey tests of the major laboratories in Hollywood have been made by the authors. The results of the most recent of these tests will be presented here.

TEST METHOD

A representative picture negative photographed on Plus X film and developed to a *IIb* gamma of 0.65, was chosen as the starting point for all tests. This girl-head negative had high-light and shadow densities of 1.48 and 0.41. These densities were read on a Western Electric *RA-1100B* densitometer, with blue printing filter, using a specially designed circular aperture, 13 mils in diameter. This small aperture has proved most helpful in scanning actual picture scenes. High-light and shadow densities reported for all films were read in this manner. With a little practice it is possible to make such readings in the picture area with a repeat accuracy of $\pm$ 0.01 density unit. Attached to a 100-foot length of the picture sample was a 10-foot length of resolving-power test negative in which the maximum resolution test chart revealed 56 lines per millimeter with sharp detail. Also, a specially prepared full-frame step-tablet was attached, the steps being increments of 0.15 density. The tablet contained 15 such steps.

This standard negative was submitted to each of five laboratories in turn and each laboratory was requested to make a master positive, a duplicate negative, a print from the duplicate negative, and a print from the original negative. It was pointed out to each laboratory superintendent that the purpose of the test was to match the two prints as closely as possible.

The original negative was not developed to the exact degree of contrast normally used by some of these five laboratories. As a

TABLE 1
DUPLICATING PROCEDURES USED IN HOLLYWOOD LABORATORIES
PRINTING AND DEVELOPING DATA

Laboratory	A	B	C	D	E
Master Positive					
Printer	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*
Speed, fpm	90	85	40	50	70
Aperture ht., in.	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$
Exposure time, sec	0.0174	0.0184	0.039	0.03125	0.0223
Exposure source	Tungsten	Tungsten	Tungsten	Tungsten	Tungsten
Lamp type	P. F. proj.	P. F. proj.	Special proj.	P. F. proj.	P. F. proj.
Lamp wattage	500	300	500	500	165
Lamp voltage	87	115	96	90	120
Developer	Picture neg.	Picture neg.	Picture neg.	Picture neg.	Special
Developing time	7′ 30″	6′ 30″	4′ 59″	7 20″	5′ 20″
Duplicate Negative					
Printer	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*	Spec. Step Printer
Speed, fpm	90	85	60	70	63
Aperture ht, in.	$^5/_{16}$	$^3/_{16}$	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$
Exposure time, sec	0.0174	0.011	0.026	0.0223	0.0248
Exposure source	Tungsten	Tungsten	Tungsten	Tungsten	Tungsten
Lamp type	P. F. proj.	P. F. proj.	P. F. proj.	P. F. proj.	P. F. proj.
Lamp wattage	400	400	165	300	100
Lamp voltage	80	115	78	90	105
Developer	Picture neg.	Picture neg.	Picture neg.	Picture neg.	Picture neg.
Developing time	4′ 00″	3′ 40″	5′ 30″	7′ 15″	6′ 25″
Prints					
Printer	Spec. nonslip	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*	B & H, Model *D*
Speed, fpm	180	85	60	70	80
Aperture ht, in.	$^3/_{16}$	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$	$^5/_{16}$
Exposure time, sec	0.0052	0.018	0.026	0.0223	0.0195
Exposure source	Mercury arc	Tungsten	Tungsten	Tungsten	Tungsten
Lamp type	AH-8	P. F. proj.	P. F. proj.	P. F. proj.	P. F. proj.
Lamp wattage	85	200	165	250	165
Lamp voltage	250	115	92	88	120
Developer	Positive	Positive	Positive	Positive	Positive
Developing time	4′ 00″	2′ 58″	2′ 30″	3′ 22″	3′ 24″

TABLE 2

DUPLICATING PROCEDURES USED IN HOLLYWOOD LABORATORIES
SUMMARY OF SENSITOMETRIC RESULTS

Laboratory	A	B	C	D	E
Original Negative					
Film type	*1231*	*1231*	*1231*	*1231*	*1231*
High-light density	1.48	1.48	1.48	1.48	1.48
Shadow density	0.41	0.41	0.41	0.41	0.41
Resolving power (max) lines/mm	56	56	56	56	56
Master Positive					
Film type	*1365*	*1365*	*1365*	*1365*	*1365*
IIb gamma	1.50	1.41	1.12	1.21	1.54
Print-through gamma	1.58	1.68	1.30	1.40	1.80
High-light density	0.69	0.65	0.54	0.45	0.55
Shadow density	2.40	2.40	1.76	1.73	2.37
Resolving power (max) lines/mm	56	56	56	56	56
Duplicate Negative					
Film type	*1203*	*1203*	*1203*	*1203*	*1203*
IIb gamma	0.59	0.57	0.74	0.67	0.69
Print-through gamma	0.62	0.67	0.82	0.74	0.66
High-light density	1.33	1.33	1.39	1.26	1.23
Shadow density	0.30	0.29	0.34	0.25	0.21
Resolving power (max) lines/mm	28	40	40	40	40
Prints					
Film type	*1302*	*1302*	*1302*	*1302*	*1302*
IIb gamma	2.33	2.26	2.30	2.46	2.50
Print from Original Negative					
Print-through gamma	1.92	2.10	2.32	2.58	2.53
Printer light number	14	12	27	23	16
High-light density	0.44	0.41	0.32	0.34	0.43
Shadow density	2.37	2.38	2.35	2.55	2.61
Resolving power (max) lines/mm	56	56	56	40	56
Print from Duplicate Negative					
Print-through gamma	1.96	2.20	2.17	2.50	2.69
Printer light number	14	12	27	21	13
High-light density	0.45	0.33	0.33	0.42	0.53
Shadow density	2.34	2.24	2.33	2.46	2.66
Resolving power (max) lines/mm	28	40	28	28	40

result, a comparison of the final over-all screen contrast at the five different laboratories has little significance. The variations in the screen contrast of the final prints are a measure of the actual printing variation rather than a true measure of the normal over-all production contrast for each laboratory. In order to compare over-all screen contrast of each laboratory's product it would be necessary to have each laboratory develop its own negative and then print that, rather than a standard test negative. The comparison of the print made from the duplicate negative with the print made from the original negative is completely valid, however, for each of the five laboratories.

The manner of reading all densities reported in this paper is that which has been in use for some time at this laboratory. The densities of those processed films which were printed onto blue-sensitive, or positive-type raw film, were read with diffuse blue light. In the case of films which were to be printed onto panchromatic film, visual diffuse densities were determined. Frayne[2] has promulgated this technique of reading densities in the manner equivalent to the printing conditions used in his excellent paper on the measurement of photographic printing density.

The resolving-power measurements were made by reading at five positions in each of several frames and using the maximum figure found in each individual frame for averaging purposes. Thus where resolution was not equally good over the entire picture area, the data reported represent the best values, rather than the over-all picture-area average. In a number of instances resolution was better in one half of the picture area than in the other half.

In Tables 1 and 2 are given the printing and developing data and the sensitometric results of the tests.

MASTER POSITIVE

Eastman Fine Grain Duplicating Positive, Type *1365*, was used for making the master positive by each of the five laboratories where tests were made. The gamma value to which this film is developed varies considerably. Fig. 1 shows the *IIb* sensitometric exposure curves and lists the manner in which this film is exposed on the type *IIb* sensitometer at each laboratory. Since this method of exposure is useful only for control purposes, it is of little importance whether the positive conversion filter is left in place or removed from the sensitometer in order to obtain more exposure. It is essential,

however, that sufficient exposure be given to *1365*, by multiple exposure and/or by removing the conversion filter, so that a reasonable number of the density steps obtained lie on the straight-line portion of the *H* and *D* curve.

In order to speed up the making of routine daily control strips, it has been recommended that the color temperature conversion filter be removed from the *IIb* sensitometer and *1365* be given four exposures. If the filter is left in place it is considered good practice to use eight exposures.

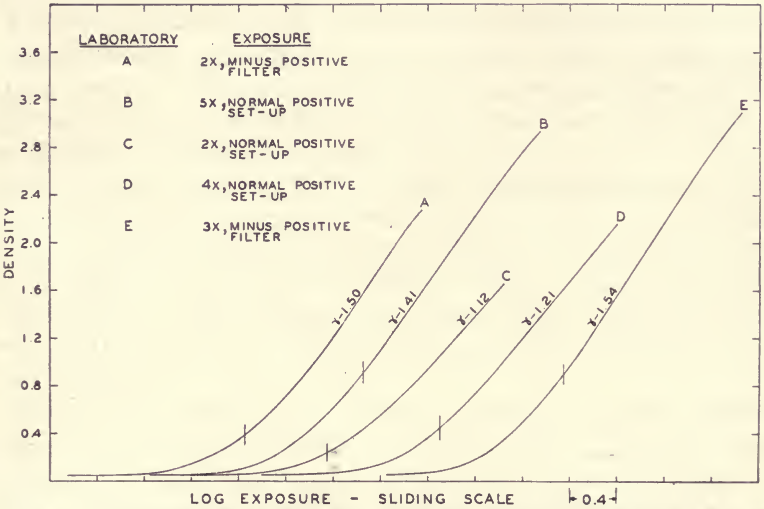

FIG. 1. *IIb* sensitometric exposure curves for Eastman duplicating positive film, type *1365*.

The *IIb* gamma values for *1365* vary from 1.12 to 1.54 at the five laboratories. The eleventh step density on the *IIb* step-tablet has been indicated on each curve by a short crossbar. This designation has been used for the reference step on all other *IIb* exposure curves in this paper.

In Fig. 2 are shown the print-through curves for the *1365* master positives. It will be seen that the print-through gamma values are somewhat higher than the corresponding *IIb* control gamma values. The *IIb* and print-through exposure strips were, of course, developed together with the picture sample at each laboratory.

The seventh step density in the 15-frame standard step-tablet has been marked on each curve in Fig. 2 so that these print-through

curves will be more useful for comparison purposes. This procedure has been continued in the subsequent print-through data given in this paper. The density of this step in the original negative tablet was 1.03.

In order to satisfy the primary requirement for good tone reproduction in the duplicating process, it is essential that all densities in the master positive lie on the straight-line portion of the print-through *H* and *D* curve. By examining the master positive highlight densities in Table 2 and by placing them on the print-through

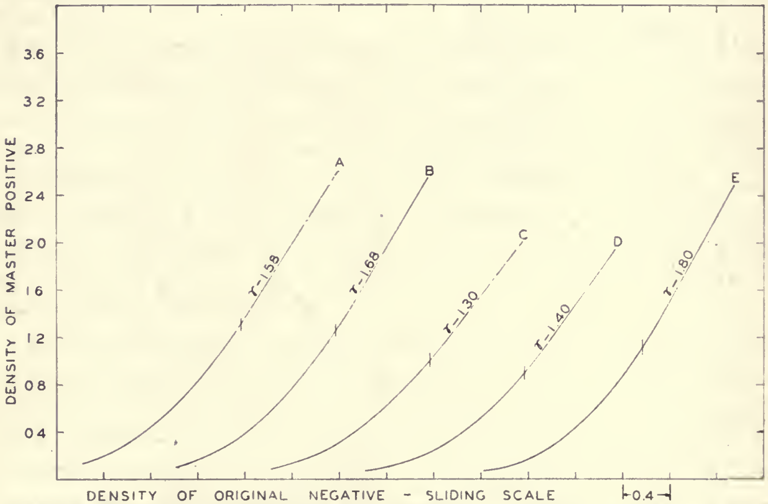

FIG. 2. Printer exposure curves for Eastman duplicating positive film, type *1365*.

curves in Fig. 2, it may be seen that in some instances there is definite underexposure of the master positive. Furthermore, by placing the shadow densities from Table 2 on the print-through curves it may be seen that considerably higher exposure might have been used in all instances without causing any loss of shadow detail due to the higher densities falling on the *H* and *D* curve shoulder. In a large number of such sensitometric analyses of master positives made over several years, there has not been noted a single instance where densities occur in the scene higher than the shoulder break density of *1365*.

Most Hollywood laboratories examine the master positive by projection, using special projection facilities in order to avoid damaging the film in any way. It is apparent that an exceedingly dark master

positive is most difficult to examine in this manner for minor defects, such as dirt. Consequently it is the natural inclination of the laboratory to print the master positive lighter, so that it can be judged more critically on the screen. This results in a high-light tone distortion due to the use of the *H* and *D* curve toe. It is believed that the benefit to be gained by many laboratories from printing the master positive considerably darker than is being done at present, and not using projection examination, would more than offset the quality loss which may result from lack of rigid screen inspection of the master positive.

The low emulsion speed of *1365*, and lack of sufficient printer light to expose this film properly, is a second cause of underexposure of the master positive. Where full advantage of the recommended method[3] of increasing printer illumination efficiency has been taken, there is no difficulty in obtaining proper exposure on *1365*.

It is apparent from Fig. 2 that a lower high-light density is allowable in those instances where lower gamma is used. As so often noted in Hollywood, the master positives from those laboratories which make the best duplicate prints are not necessarily the darkest master positives. This is true because of the wide variation in gamma used for the master positive and the consequent variation in toe-break density.

Equally good master positives may be made on *1365* at print-through gamma values ranging from 1.00 to 2.00. It is only necessary that the duplicate negative gamma value be balanced accordingly. The minimum allowable exposure necessary to place all densities in the master positive on the straight-line portion of the curve remains quite constant as the degree of development increases. Thus the effective emulsion speed is not increased by working at a higher gamma value, as is often erroneously thought to be the case for this film.

All laboratories make printer light changes from scene to scene in printing the master positive. If timing of a negative is first done in the making of a release print, it should be possible to use exactly the same light changes, with a much increased exposure source, in making the master positive. The lower gamma of the master positive will result in a lower density increment per printer light, but this compression of the density scale is, of course, as it should be. The printing scale for *1365* should never be adjusted so that the density increment per printer light becomes the same as that obtained on *1302*.

If this is done an abnormal increase of density in the darker scenes and lessening of density in the lighter scenes will be evident in the final print. Considerable effort is expended by some laboratories in selectively timing the master positive; sometimes light changes are made between scenes that do not call for light changes in the release print timing. This is inconsistent and is certain to result in lack of exact duplication of the print made directly from the original negative, unless a compensating light change is made in printing the duplicate negative or the print from the duplicate negative.

Since almost all laboratories strive to make the duplicate negative and the final duplicate print without making printer light changes, the production of a correctly timed master positive is of great importance.

Many laboratories have the master positive printer exposure scale and over-all illumination so adjusted that the printer lights used for the release print are automatically correct for the master positive printer. Of course, the same printer setup cannot be used for both jobs. By properly attenuating the illumination without affecting the relative exposure scale, the same printer that is set up for printing master positives may be used for making release prints. Obviously if the lightest scene in a master positive is printed dark enough to place the high lights on the straight-line portion of the curve, then some scenes will be considerably darker than this minimum allowable high-light density. This is necessary if a "one-light" duplicate negative is to be made.

The resolving-power data in Table 2 show that 56 lines per millimeter, which was the maximum resolution chart used in the original negative, may still be resolved in all five master positives. There is undoubtedly some loss in resolution but it is less than could be measured by the test charts used.

DUPLICATE NEGATIVE

About two years ago a change was made in the emulsion characteristics of Eastman Fine-Grain Panchromatic Duplicating Negative Film, Type *1203*, which was designed to accomplish three aims.

1. To increase the latitude, or length of avilable straight-line portion of the H and D curve.

2. To increase the developing time necessary for normally used gamma values. This was desirable in view of the abnormally short developing times which were dictated by economic considerations at some laboratories.

3. To give better uniformity and freedom from flicker, unevenness, etc., in the screen image of duplicate prints.

Figs. 3 and 4 show the *IIb* and print-through *H* and *D* curves for *1203* at five laboratories in Hollywood. A single normal positive exposure was used on the *IIb* sensitometer in all cases. The print-through curves have generally higher gamma values. In comparing the contrasts of the duplicate negative at the several laboratories it is apparent that the *IIb* gamma values are misleading. This accounts for much confusion in the minds of those laboratory men who

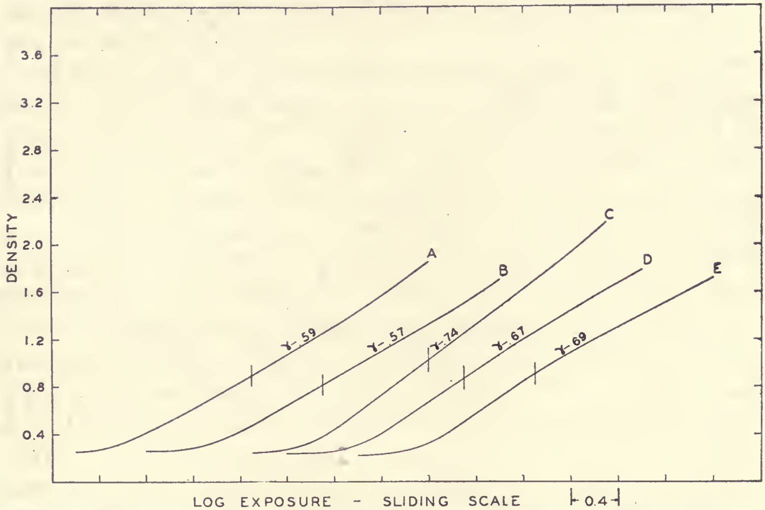

FIG. 3. *IIb* sensitometric exposure curves for Eastman fine-grain panchromatic duplicating negative film, type *1203*.

are well aware of the large differences in contrast in the master positives from various laboratories and who cannot understand how this has been compensated for in the duplicate negative when they compare the *IIb* gamma values of the latter.

If the shapes of the curves in Fig. 3 are compared with the similar *IIb* exposure curves for *1203* which were published by Ives and Crabtree[1] in September, 1937, the increase in latitude in the current film will be readily seen.

In order that the requirements for correct tone reproduction be satisfied, it is essential that the full scale of densities in the original negative be placed entirely on the straight-line portion of the duplicate negative. The effect of deviations from this manner of exposure

for the duplicate negative may be obtained by the use of a graphical method for the study of tone reproduction described by Jones.[4]

A large portion of all original motion picture camera negative is exposed so that the toe of the *H* and *D* curve is utilized, and, in fact, so that there are generally shadow areas to be found, which, upon measurement, show no silver density whatsoever. In order that a satisfactory duplicate negative be made of such an original negative, the duplicate negative must be so exposed that the minimum density in the original negative, which was base density, shall become the toe-break density, or somewhat higher, in the duplicate negative.

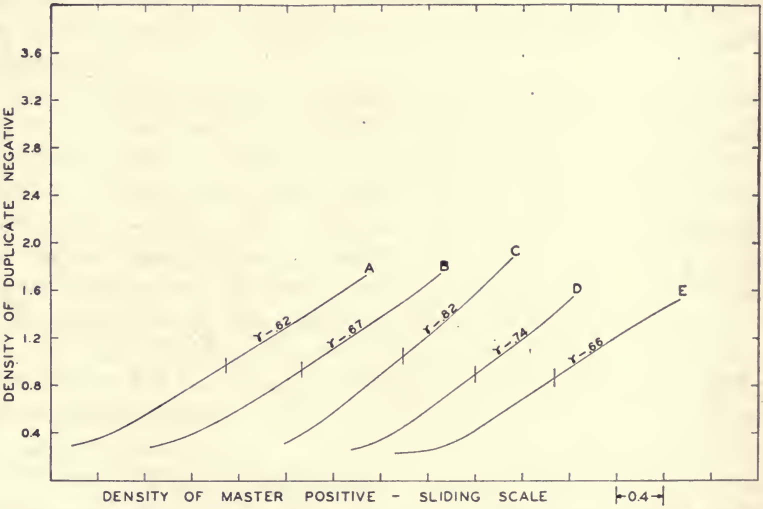

FIG. 4. Printer exposure curves for Eastman fine-grain panchromatic duplicating negative film, type *1203*.

Obviously, therefore, the duplicate negative would be darker than the original negative and would require a higher printing light in order to given an exactly matching print. This fact is well known to most laboratory men. However, the erroneous impression still exists in many places that a duplicate negative, made from even a badly underexposed original negative, should match the original negative, density for density, and, if made perfectly, should print on the same printing light. It is true that, because of the lower toe break of the duplicating negative film, compared with that of most picture negative materials, a correctly exposed duplicate negative may have lower printing density than the original negative from which it was made, in those instances where the original negative

had shadow density at or about the toe break. There are many instances where the original negative, being overexposed, will be considerably heavier in density than a correctly made duplicate negative.

As pointed out by Ives and Crabtree,[1] there is a difference in the ratio of visual to effective printing densities for *1203* and the ordinary picture negative films. This difference causes a compression of the density scale in the duplicate negative relative to the original negative, if densities are read with visual light. If, however, densities are read with blue printing light, as described earlier in this paper, this discrepancy largely disappears and the actual printing behavior of the duplicate negative relative to the original negative may be more accurately predicated.

There are special instances where the application of the classical methods of tone reproduction cannot be applied to the duplicating process. For example, in the making of ordinary dissolves, lap dissolves, and other such special effects, oftentimes the entire scene is not duplicated. If only a portion of the scene which is to contain the special effect is duplicated, it is necessary that there be no printer light change at the point of juncture of the original negative and the duplicate negative. If there is a printer light change at this point, it is almost surely to be noticeable as a "bounce" in illumination on the screen. Consequently the printing densities of the duplicate and original negatives must be as nearly equal as possible. This implies that if the original negative were badly underexposed it is necessary to make an underexposed duplicate negative to match it. The resulting superimposition of the toe region of the duplicate negative curve on the toe of the original negative results in serious loss of contrast in the shadow areas.

In the making of certain trick shots, where black velvet covers large areas of the scene being photographed, and double exposure is used in making a composite duplicate negative, usually in an optical printer, it is necessary that there be no printed-in density from the black velvet in the duplicate negative. Therefore, one must expose so as to obtain clear film base in the duplicate negative in those areas covered by black velvet in the original scene. This procedure makes it very difficult to obtain linear tone reproduction in the duplicate negative for the points of interest in the scene. However, by proper lighting, this technique, used so successfully in such pictures as "The Invisible Man" and many others, both in black and white and color, is accomplished with very little degradation in quality.

If the high-light and shadow densities of the duplicate negatives listed in Table 2 are fitted onto the print-through curves in Fig. 4, it will be seen that, just as in the case of the master positive, there is a general tendency to underexpose the duplicate negative. This results in a loss of shadow detail in the duplicate print. It is believed that this general tendency to underexpose the duplicate negative stems partially from the feeling that the duplicate negative must be no darker (as judged by printing behavior) than the original negative.

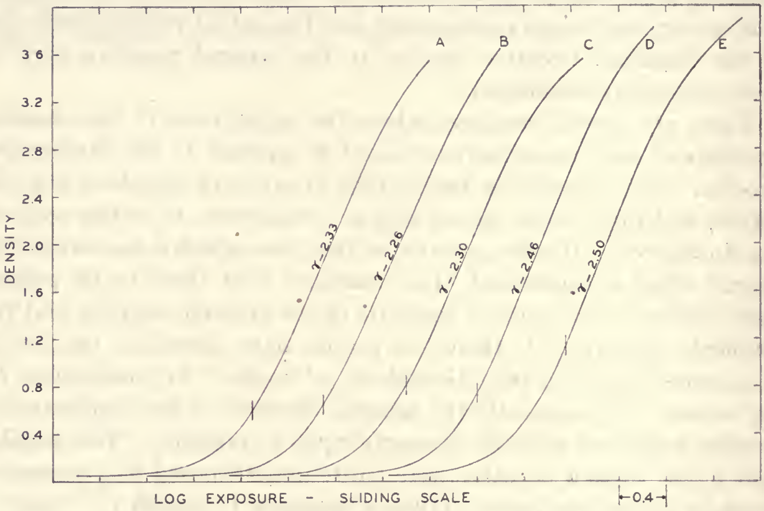

FIG. 5. *IIb* sensitometric exposure curves for Eastman fine-grain release positive film, type *1302*.

The resolving-power data in Table 2 indicate a considerable loss in resolution in making the duplicate negatives from the master positives. The maximum resolving power of *1203* emulsion is approximately 150 lines per millimeter when processed in a normal manner. The loss cannot be explained satisfactorily therefore in terms of emulsion limitations. At the present time the cause or causes of this loss of resolution in contact printing of duplicate negatives is not known.

The *IIb* sensitometric control curves for the *1302* prints made at the five laboratories are shown in Fig. 5. The print-through gamma values for the prints from original negatives and the prints from duplicate negatives are listed in Table 2. For the sake of brevity, the prints shall be referred to as "original" and "duplicate" prints.

Since the print-through curves consist of the print densities plotted versus the effective printing densities of the original and duplicate negatives, respectively, one would expect to find no difference in the gamma values of the two print-through curves. However, the print-through gamma of the original print is lower in some instances and higher in others than that of the duplicate print. We interpret this to mean that measurement of the negative densities with diffuse blue light, as done on the Western Electric *RA-1100B* densitometer,

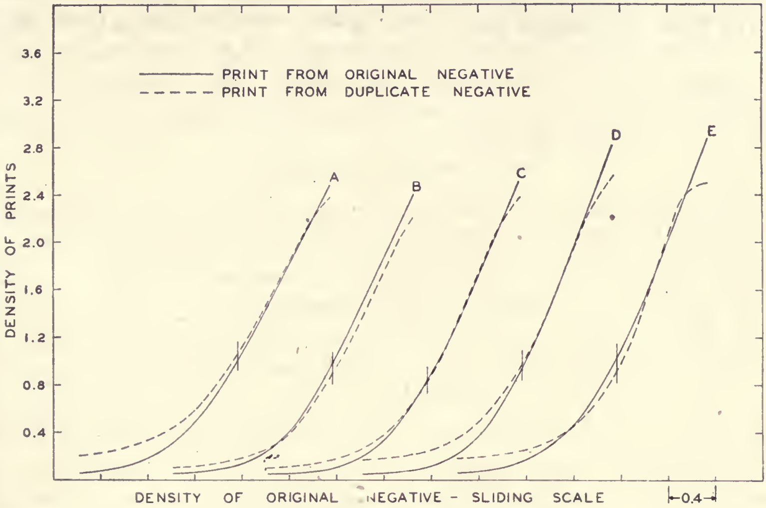

FIG. 6. Over-all sensitometric comparison of prints from original negative with prints from duplicate negatives.

while being a close approximation to the true printing densities, is not entirely accurate. The variation in the ratio of the two print-through gamma values may be due in part to the known variation in image color obtained on the duplicate negative at the different conditions of processing. The print-through curves for the original prints are shown in Fig. 6; those of the duplicate prints are not shown in the figures.

In Figs. 6 and 7 are shown two commonly used methods for measuring sensitometrically the degree of fidelity of the duplicating process. In Fig. 6 the densities of both original and duplicate prints (step-tablets) are plotted versus a fixed abscissa—the densities of the original negative. If perfect tone reproduction is achieved throughout the entire print density scale, the two curves should

exactly superimpose. Fig. 7 utilizes a manner of plotting the data which emphasizes the departures from perfect tone reproduction. Here we find the same two sets of print densities used in Fig. 6 plotted versus each other. In the case of perfect tone reproduction, the dashed line at a 45-degree angle would be obtained. The actual comparisons of original and duplicate prints at five Hollywood laboratories are indicated by the solid curves.

An analysis of these curves shows that, in general, the over-all contrast comparison, indicated by the deviation of slope of the solid curve from the dashed line, is very good. This is the natural result

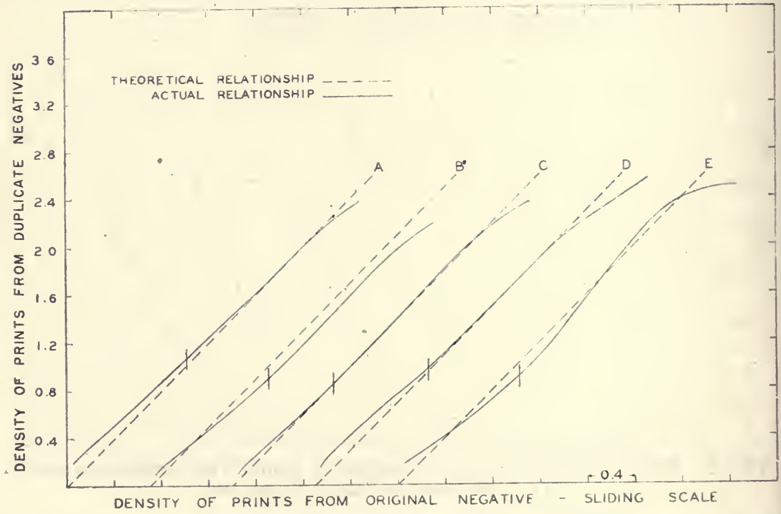

FIG. 7. Over-all fidelity of tone reproduction.

of much day-to-day examination of finished print comparisons and the making of small adjustments in duplicate negative or master positive contrast. It is not difficult to detect small errors in over-all contrast by visual examination of the finished prints.

The fidelity of tone reproduction in the extreme high-light and shadow regions is not so good in all cases. Underexposure of the master positive results in the lack of clean high lights in the duplicate print. Underexposure of the duplicate negative results in loss of shadow detail and lack of sufficiently dense blacks in the duplicate print. It is very difficult to diagnose correctly these common faults by screen examination of the finished prints. One is much too prone to call the fault an error in over-all contrast, when, in actuality, it is

an error in exposure, in one or both steps in the process. A true error in over-all contrast is very easily discernible and likewise easily remedied. Sensitometric analysis of the type shown in Fig. 7 is a rapid aid to diagnosis of the source of the more common errors of exposure.

The resolving-power measurements in Table 2 show that the original prints have retained 56 lines per millimeter in all cases but one. Likewise, there is little additional loss in printing from the duplicate negatives. The total loss of resolution in the duplicate prints as compared to the original prints is large enough so that it may be detected upon critical screen examination if the subject matter contains contrasty fine detail. A notable example is women's jewelry, with flashing pinpoint high lights. It has been observed that this type of subject matter is often less sharp in duplicate prints than in original prints.

GENERAL CONSIDERATIONS

For the most precise sensitometric evaluation of the duplicating process it is necessary to consider the "adjacency" effects, which in the case of unidirectional travel of motion picture film in a developing machine are known more specifically as "directional" effects. This has been discussed in this JOURNAL by Weiss.[5] Special directional effect tablets were included in the test negative used in this work, but no effort has been made to incorporate those data in this paper. The full-frame step-tablet used for these tests, while not exactly indicative of the conditions found in the actual picture scene, is useful for obtaining comparative results and for determining the primary causes of degradation in the duplicating process.

While this paper is confined to a consideration of the picture-duplicating process, it is apropos to mention that since the variable-density sound-recording process is based on a linear relationship between original negative exposure and final print transmission, all statements regarding the proper exposure and development of the master positive and duplicate negative apply equally well to the duplication of this type of sound track. As for the variable-area sound track, the best values of density in the master positive and duplicate negative should be determined by cross-modulation tests. If this cannot be done, it is advisable to make listening tests, with emphasis on elimination of sibilant distortion, in order to set up the optimum-density requirements. It is usually more convenient to establish a fixed density in the duplicate negative which is the highest value readily obtainable without accompanying printer flare, and then to

vary the density of the master positive sound track until the best conditions are reached.

PRACTICAL SUGGESTIONS

For the establishment of correct picture exposure and development conditions for the master positive and duplicate negative, a few simple steps may be enumerated.

1. Choose a development condition which gives a print-through gamma value on Fine-Grain Duplicating Positive Film, Type *1365* in the neighborhood of 1.20 to 1.50. A satisfactory *H* and *D* curve with linearity comparable to those shown in this paper should be achieved. Establish a means of controlling the development, such as by the use of the *IIb* sensitometer.

2. Make exposure tests using typical camera negatives and determine, if possible by spot measurement in the picture area, when the minimum density in *1365* lies above the toe break. If this cannot be done, determine the exposure just necessary to produce the toe-break density on *1365* when printed from a density of 1.50 on the camera negative. This can be done by using a *IIb* step-tablet. This exposure should be established as the middle of the available *1365* printing scale. This arbitrary value of negative density is representative of the average high-light density of a fully exposed motion picture camera negative.

3. Make print-through exposures on *1365* to serve as a control on the over-all development and printing condition. The *IIb* sensitometer is useful as a control on the developer alone.

4. Print a correctly exposed and developed *1365* picture scene onto Fine-Grain Panchromatic Duplicating Negative Film, Type *1203* so as to obtain minimum density above the toe break. This may be approximated by visual comparison of the picture scene with known step-tablet densities. Develop for a series of times, so as to obtain print-through gamma values of, for example, 0.60, 0.65, 0.70, and 0.75. Print these negatives, and also the original negative and compare by projection. Determine exact duplicate negative gamma necessary by making further tests.

5. Make print-through exposures and *IIb* exposures, if possible, on *1203* to serve as controls on the development and printing operations.

6. Plot the final print-through data as shown in Fig. 6, and determine, by comparison of picture and step-tablet densities, if

possible, whether exposure and development conditions are correctly adjusted.

CONCLUSIONS

The tests reported here, as well as all others made over a period of several years, have shown that the lack of correct tone reproduction in the motion picture duplicating process may be traced by sensitometric analysis to two primary causes:

1. Underexposure of the master positive.
2. Underexposure of the duplicate negative.

In general, the fidelity of tone reproduction obtained at the five Hollywood laboratories studied in this survey is of very high quality. In most instances it is not possible to determine, by visual inspection, which, of the two prints made by each laboratory, is the print of the duplicate negative and which is the print of the original negative.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the five laboratories where the tests reported here were made. Thanks are due Mr. Ralph Westfall, who aided in compiling the data.

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DISCUSSION

MR. R. M. CORBIN: There have been many people who felt that sensitometric data were not too useful in this kind of work but I think they were led to that feeling by the use of time scale or long time exposures. You have to take into account a great many things that may happen to the sensitometric measurements in order to have them mean something. Only part of these factors are brought out in this paper.

MR. JONES: In the case of images, does the image spread by reason of a higher density, and is there any distortion of line drawings?

MR. CORBIN: With line drawings, an image spread or shrinkage occurs in accordance with the density used; of course, you can get cancellation by proper selection of the negative and print densities in the same way that you do in variable-area sound recording.

TELEVISION STUDIO LIGHTING*

W. C. EDDY**

Summary. *The three basic laws of television, i. e., mobility, flexibility, and instantaneity, are best represented in the requirements for a satisfactory lighting system for the video medium.*

While the fundamentals of lighting techniques for the stage and for motion pictures remain unchanged, the presently accepted system of remote-control overhead lighting in television relegates to one operator both the control and complete operation of the entire system. By flying the equipment from a unique gridiron, it is possible to keep the studio floor clear for camera operation and stage settings, while from an overhead observation and control position the lighting control engineer can, at a flick of the finger, create and recreate at will the lighting effects required at a given moment.

Television studio lighting has in the past few years moved from the brute-force flat-illumination problem imposed by low-sensitivity cameras to the more specific requirements of the extremely high-sensitivity image-orthicon and orthicon chains. The need for high-intensity mercury-vapor lamps and over-all lighting levels of better than 1500 foot-candles incident has given way to a superflexible system capable of creating the artistic effects now required in studio work. The Tele-Lite of Television Associates, Inc., now installed in three postwar television studios, is typical of this new departure in remote-controlled illumination designed and tested in television broadcast studios.

The advent of television, with its demands for a new high in continuity of production, made apparent the need for a lighting system that would match the fluid spontaneity of the video cameras. While it was true that the basic requirements of stage and motion picture lighting remained unchanged, and that the type of light was the same, special equipment and special techniques for handling this new departure in lighting had to be created.

From 1934 to 1937, television lighting had limited itself to the art of pouring on front light in heretofore unheard-of quantities in a vain attempt to overcome the insensitivity of the early iconoscope cameras. Little or no choice was given or asked as to the methods used. Light and more light was the watchword, for it was apparent that light was helping to bring the television screen out of the shadows and indefinition of the scanning-disk days.

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* Presented Apr. 22, 1947, at the SMPE Convention in Chicago.

** Director of Television, WBKB, Chicago, Ill.

During this era of development, lighting equipment in all its standardized forms, and much that was not standardized, was intermittently brought into play in an attempt to overcome low mosaic sensitivity. Sun spots, Hollophanes, Broads, Inkies, Hi-arcs, and Kleigels could be found on stages in every experimental studio. Overhead in the acting area, massive arrangements of home-designed fixed ceiling units insured that no dimension of the stage would long be without its flood of searing light, and, coincidentally, heat. While the design of these ceiling units varied widely from one broadcast studio to the next, they did have several characteristics in common.

1. They were fixed in position, demanding that the subject be placed under the lights rather than bringing the light to the object being televised.

2. They were, in general, a noncharacteristic type of illumination which did not and could not produce any but the faintest differential between high light and shadow, a major concession on the part of the lighting engineer to the erratic black-and-white response of the television screen of those days.

3. Since they were fixed in position, there was little possibility of any but the crudest attempts at back and side lighting. Whether or not the pioneer televiewer would than have recognized or appreciated such techniques in that era of low fidelity cannot be guessed. Certainly the engineers of the period were more than glad to consider lighting in only one category, "quantity", and to overlook as well as discourage the so-called artistic attempts of the production group in introducing high light and shadow into the television-picture business.

This, briefly, is a résumé of television lighting in the late thirties: Immobility in equipment; insensitivity in camera equipment; with every licensee experimenting with new methods and devices to provide lighting levels of from one thousand to two thousand foot-candles incident.

In 1937, the field tests of the Radio Corporation of American and the National Broadcasting Company in the New York Metropolitan area brought television before the general public for the first time. It was then that the subject of controlled lighting was added to television's already extensive list of problems. From fan mail, telephone calls, and personal visits, it was immediately evident that the public, the ultimate consumer, wanted more than a high-fidelity reproduction of a kitchen chair or a flat-lighted engineering test pattern as its picture fare from this new medium. The public wanted, and so stated

in no uncertain terms, a reasonable facsimile of the lighting and camera work to which it had been educated by motion pictures. With the sensitivity of the cameras increasing by the week, with new techniques being devised in stagecraft, new technical equipment available in control rooms, it was easily apparent that if lighting were to stay abreast of the rapidly developing video field, a new and radical approach to the illumination problem had to be attempted.

Television lighting, by popular acclaim or popular criticism, became a point of issue. The wise broadcaster recognized the need and took steps to find an answer. With every competitor using

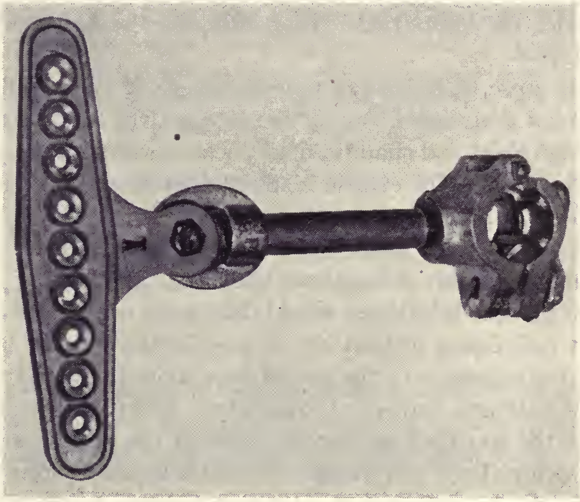

FIG. 1.

camera equipment of duplicate sensitivity and fidelity, it was patent that to the broadcaster who could couple the best in technical facilities with an artistic, well-composed, and well-lighted picture would go the best of competitive television contracts.

For that reason a survey was made not only of the available systems but with a view to designing an ideal system as well. This analysis of an acceptable television lighting system brought out a list of ten basis specifications for which an answer had to be found. These requirements were:

1. All lighting should be fully controllable from a remote position in the studio, preferably a catwalk above the studio floor.

2. The basic lighting system should be made up of incandescent units because of the generally high camera sensitivity in this color spectrum.

3. All lighting should be controlled from one position and by one operator who could be trained and held responsible for both the artistic aspects as well as the engineering phases of the assignment.

4. The accepted system should be capable of developing foot-candle readings of from 50 foot-candles incident to better than 1500 to cover the wide range in sensitivity between the image-orthicon camera and its antithesis, the iconoscope.

5. Sufficient light should be available in the system selected to light not only the stage in work, but to permit the presetting of at least one successive full-sized stage with normal illumination.

6. A wide flexibility in type and character of light should be provided to accommodate the characteristics of the several types of cameras being used or contemplated for television.

7. This lighting system should be effective in any part of the studio with controlled back light, side light, overhead, and front light available from any possible location on the set, throughout the course of the telecast.

8. The unit should be light in weight, easily adaptable to new equipment, reasonable in unit cost, and simple in operation.

9. Provision should be made to reduce light levels without resorting to dimmers during the long rehearsal periods required for a telecast. At the same time the angle of distribution, the relationship of high light to shadow, and the general effects to be achieved under broadcast conditions should remain unaltered to permit technical checking during rehearsal periods.

10. The system should be controlled from an electrical switching panel that would permit instant as well as silent energizing of any or all units in the studio, without disturbing the camera circuits. In addition, a storage system of electrical controls should be incorporated in this switching panel to allow an accurate reproduction of the lighting system and the position of the units devised during rehearsals to be repeated some hours later on the evening's telecast. In addition to all this, the multiple-switch panel handling a possible peak load of 250 kilowatts should be absolutely silent and dependable in operation.

It was in answer to these specifications derived from actual studio experimentation that the normal stage-lighting equipment, common

to motion picture studios, was in the main rejected. In the first place, the technique of lighting and the equipment used in motion pictures related to a picture system that could record and support high-contrast scenes. In addition, individually operated units, by reason of their bulk and floor-mounted position, could not be expected to produce satisfactory lighting over an uninterrupted period of telecasting, without the benefit of frequent resetting and checking common to the motion picture set.

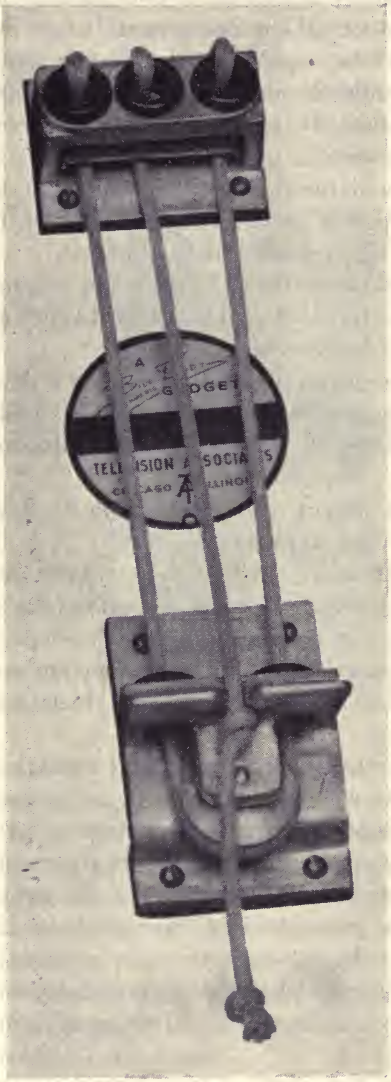

FIG. 2.

Third, there was not room on studio floors for the technicians and apparatus required for this normal type of floor-lighting equipment, without restricting the movement of cameras and microphone booms. Under test, it was proved that the individual *ad lib* lighting, as produced by a series of independent floor operators, was at its best problematical for commercial television, where "retakes" are impossible. If everything went right; if each operator could be counted on to have his light, of the proper value, focused on the proper place, all went well—but let the slightest misplacement of the individual units occur, and the monitor screens of the shading console went into violent oscillations because of hot spots, or the picture resolved itself into a panorama of dull gray and faded black.

Based on actual television studio experience, during both

the early experimental period as well as the postwar commercial era, a remote-controlled system of television lighting was gradually evolved to answer the problems of television studio work. This system, controllable from a remote position through its arrangement of fair-leads, Fig. 1, and anchor blocks, Fig. 2, with the control center located in any convenient part of the studio, appeared to be a reasonable answer.

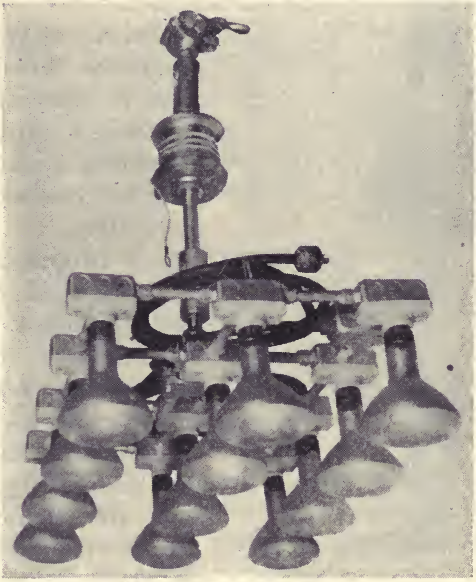

FIG. 3.

Second, by reason of the multiplicity of sockets (12 to a unit, 6 to a circuit), Fig. 3, lamps of any type or color coeffiicient could be used. In addition, a special adaptor made possible the installation and use of remotely controlled spots, Fig. 4, as well as special-effect lights with no further complication or restriction than that found in floodlights.

In television studios, lighting problems were centered in one man. The lighting engineer was given not only the necessary control equip·ment, but the accompanying responsibility as well. Let us see how this system approximates the ideal.

1. By relamping, this system can be operated in any range from 50 to 2000 foot-candles per set.

2. By proper arrangement of sufficient units on the gridiron, multiple sets can be lighted simultaneously with back, side, and front

FIG. 4.

light, completely flexible and maneuverable in the hands of the control operator.

3. The equipment is light in weight—35 pounds for a 6-kilowatt unit, which is less than 6 pounds dead weight per kilowatt.

4. It is cheap on a mass-production basis, and is foolproof in operation. There are no motors to cause interference, no cooling system to leak, no complex controls to become inoperative.

5. A two-circuit system has been incorporated to permit half-light setups without varying the color temperature of the lamps by resistance reduction. By this means the studio-lighting level can be reduced for rehearsal periods at the same time maintaining an accurate reproduction of angle of distribution and high light to shadow relationship.

In completing such a package system of television lighting, it was necessary that a master switching panel be designed to control the electrical circuits. After much experimentation with silent breakers, mercury switches, and other panel devices, a system of "momentary contact controllers" was adopted, each switch controlling a remotely located breaker, two to each lighting

unit. While it may seem that such a complex arrangement was an unnecessarily expensive method of obtaining noiseless switching, it did have advantages which made its installation worth while. By using these magnetically held breakers, the switching system could be limited to low voltages, low-current circuits, thus reducing electrical "womps" on sudden changes of lighting load.

At the same time all heavy-duty wiring to the lights came direct from the breaker panel to the unit, resulting in a large saving in heavy wiring costs. By adopting such a system, it was further possible to incorporate a series of mechanical holding breakers which, when actuated, would allow operation of selected groups of units with the facility of a single unit. To complete this control board, a monitor receiver was installed as part of the assembly, to permit the operator first-hand analysis of the illumination on the stage in work.

While it is evident that no system of lighting or combination of systems can, in themselves, insure satisfactory results, it is believed that the Tele-Lite system described has for the first time provided the telelighting engineer with equipment necessary to his assignment.

With the increased contrast now available in modern television receivers, and the high sensitivity of today's cameras, it is to be expected that new techniques in lighting, approximating the standards of motion pictures, will soon be displayed on receiver screens. By providing a lighting system tailored to the requirements of the video arts, studio lighting under the guidance of a qualified technician is now able to parallel the technical advances of the engineering and production phases of television.

LEAD-SULFIDE PHOTOCONDUCTIVE CELLS FOR SOUND REPRODUCTION*

R. J. CASHMAN**

Summary—*Lead-sulfide photoconductive cells developed during the war at Northwestern University show considerable promise in sound reproduction. These cells, in contrast with cesium-oxide phototubes used in present systems, exhibit a much higher signal-to-noise output and a lower impedance. The cell noise is not increased in the presence of background radiation. The frequency response is excellent and the sensitive surface is undamaged by high-light levels. As a result of the high infrared sensitivity of these cells, an indirectly heated exciter lamp has been developed which operates with an ordinary 60-cycle filament transformer. Radio-frequency or direct-current heating of exciter lamps is thus not required.*

The detector used with optical sound tracks has been almost exclusively the cesium-oxygen-silver photoemissive cell. The selenium-photovoltaic cell, such as is used in the modern exposure meter, has had limited use, particularly in Europe, but the high capacitance and consequent poor frequency response has prevented its use in high-fidelity sound systems. Recently, the so-called blue-sensitive photoemissive tube made with a cathode of cesium-antimony alloy has been used as a detector by several investigators. Unfortunately the extremely high sensitivity of this tube in the blue and ultraviolet is almost exactly offset by the feeble output of these radiations from tungsten-filament exciter lamps. The development of an exciter lamp with a high output in the blue region of the spectrum would make the performance of the cesium-antimony phototube much more impressive.

Two new photoconductive cells made of thallous sulfide and lead sulfide have been recently released by the Government.[1] These cells were developed during the war at Northwestern University largely under contract with the Office of Scientific Research and Development. The lead-sulfide cell is particularly adapted for use in sound reproduction by virtue of its high sensitivity, low noise, low impedance, excellent frequency response, and general sturdiness in the presence of background radiation.

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* Presented Apr. 21, 1947, at the SMPE Convention in Chicago.

** Northwestern University, Evanston, Ill.

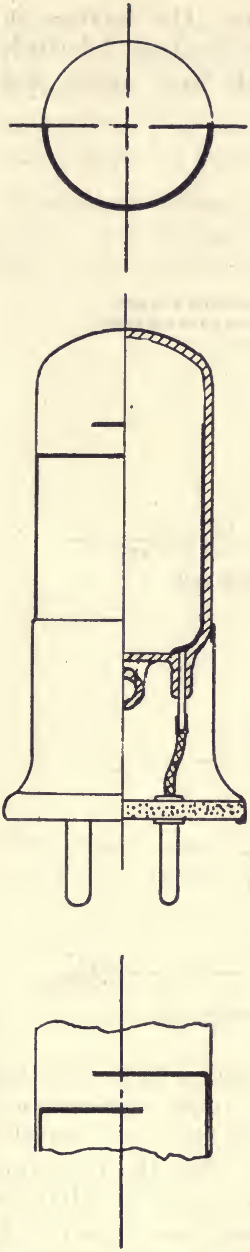

FIG. 1. Lead-sulfide cell.

CHARACTERISTICS OF LEAD-SULFIDE CELL

A detail drawing of one type of lead-sulfide cell is shown in Fig. 1. The lead sulfide is located on the inner wall of the envelope between the parallel conducting strips. The area of the sensitive surface depends on the application. For most sound systems areas of $^1/_4 \times {^1/_4}$ inch to $^1/_2 \times {^1/_2}$ inch are satisfactory. The resistance (in the dark) of the cells may be varied from about 0.1 to 10 megohms depending on the geometry and method of construction. Since no internal structure exists inside the tube, internal microphonics are almost nonexistent.

Spectral Response.—The spectral response of the lead-sulfide cell is shown in Fig. 2. For comparison purposes the spectral characteristic of the cesium-oxide-silver phototube is shown. Ordinates are in arbitrary units. One of the most outstanding characteristics of the lead-sulfide cell is its high infrared response. It will be observed that in comparison to the threshold position at 1.2 microns for the cesium-oxide-silver phototube, the lead-sulfide cell responds over a range of three octaves farther down in the frequency spectrum to 3.6 microns. The response from 2.5 to 3.6 microns is decreased somewhat by the absorption of the glass envelope.

Frequency Response.—A typical frequency-response curve from 30 to 10,000 cycles is shown in Fig. 3. The modulated flux used for these data was 1 microlumen from a tungsten filament at 2870 degrees Kelvin. The polarization voltage applied in series with

the cell and equal load resistor was 45 volts. The decrease in response at 10,000 cycles which in this instance is about 7 decibels is caused partly by the capacitance of the cell, base, socket, and connecting leads.

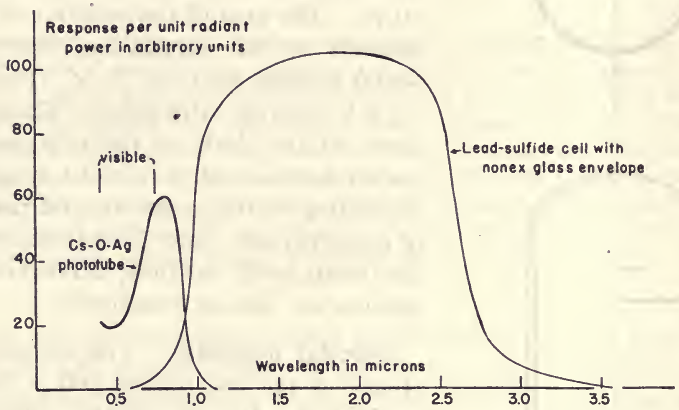

FIG. 2. Spectral response of lead-sulfide cell.

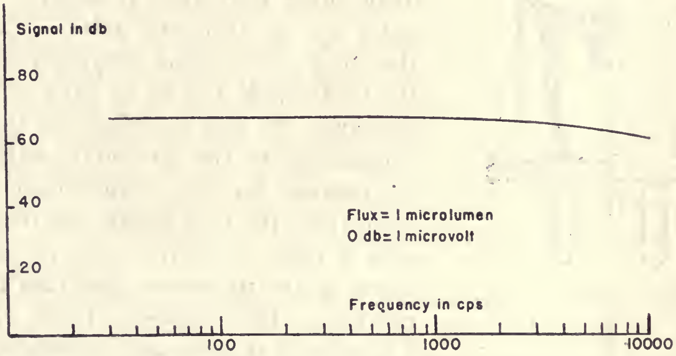

FIG. 3. Frequency response of lead-sulfide cell.

Under identical test conditions cesium-oxide-silver phototubes deliver a signal 15 to 30 decibels lower over this range of frequencies.

Cell Noise.—The noise generated consists of two parts, namely, thermal or Johnson noise and current noise. For the polarizing voltages normally used in sound reproduction (45 to 90 volts) the total cell noise is not more than a few decibels above 1 microvolt. Actually the noise generated is a function of the area of the sensitive

surface and varies inversely with the square root of the sensitive area. The signal-to-noise ratio for a constant flux varies with area in the same way. Therefore the cell area should be no larger than is required by the optical system. The current part of the noise is also frequency dependent and decreases with increasing frequency.

Response Versus Illumination; Background Effects.—The response varies linearly with illumination up to values of 20 to 40 foot-candles and thereafter seems to follow a square-root relation.

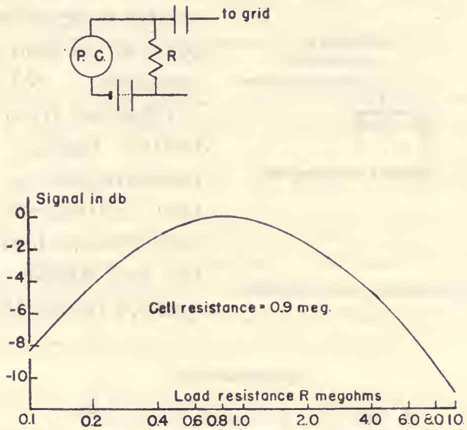

FIG. 4. Signal versus load for lead-sulfide cell.

When background illuminations are present from sources rich in the infrared, the signal output is decreased somewhat. In contrast to photoemissive cells in which the noise increases with background illumination the noise from the lead-sulfide cell is lowered.

Signal Versus Load Resistance.—The variation of signal output with load resistance for a constant input flux is shown in Fig. 4. Although optimum signal is obtained with a load resistance equal to cell resistance, the former may be varied considerably without a large decrease in signal. This characteristic may be utilized in sound systems without preamplifiers located near the cell to improve the over-all frequency response. By using a low-impedance input the effect of capacitance shunting at the higher frequencies may be reduced and a relatively long connecting cable to the amplifier may be used.

INDIRECTLY HEATED EXCITER LAMP

The high infrared response of the lead-sulfide cell enables it to respond to sources of radiation at much lower temperatures than was possible with any previous photoelectric cell. In view of this characteristic an indirectly heated excited lamp has been developed in which the heating current is supplied by an ordinary filament transformer. The details of one type of lamp are shown in Fig. 5. A lead-sulfide cell operating in conjection with this lamp whose filament is maintained at around 1500 degrees centigrade delivers a signal voltage equal to or higher than that from conventional systems with an exciter lamp filament temperature of around 2700 degrees centigrade. No 120-cycle hum is observed from the indirectly heated lamp. Conventional radio-frequency or direct-current heating of exciter lamps may thus be eliminated by using the lead-sulfide cell as detector and the indirectly heated lamp.

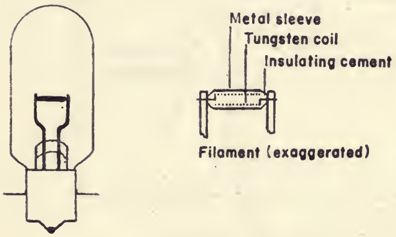

FIG. 5. Indirectly heated exciter lamp.

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[1] CASHMAN, R. J.: *J. Opt. Soc. Amer.*, **36**, 356A (1946).
[2] National Electronics Conference, Chicago, Ill., 2 (Oct. 1946), p. 171.

DISCUSSION

MR. LEWIS: As I understand it, this cell places before the film distributors or printers the question of whether to put out dye tracks or silver-salt sound tracks on their films. Is that correct?

DR. R. J. CASHMAN: I don't believe I am in a position to give a satisfactory answer to that question. The dye sound track has not been tried with this cell. It is well known that the dye sound track has a high transmission, around $^8/_{10}$ or $^9/_{10}$ of a micron. I have not found any data in the literature showing absorption or transmission characteristics in the region where this cell would come into its own. If there were an absorption band at 2 microns or $1^1/_2$ microns, then the contrast might be great enough to make the cell work very well with a dye sound track.

DR. J. G. FRAYNE: I should like to ask Dr. Cashman to tell us how the output versus the input compares with the standard setup.

DR. CASHMAN: Thank you for reminding me of that. The output or signal voltage developed by the cell is a function of the intensity of the impinging radiation. It is linear up to about 30 foot-candles. The relation from there on to higher

intensities, like that of the sun, follows a square-root law, but up to about 30 foot-candles the cell is quite linear.

There is another point in regard to background effects. No matter what the current is due to, the phototube increases its noise in proportion to the square root of the current through it. The current could be caused by background radiation. The lead-sulfide cell, on the other hand, decreases in noise with background. The signal drops somewhat with background but the signal-to-noise ratio is reduced very little.

DR. E. W. KELLOGG: From your description I didn't understand whether this is a thin film or not. You spoke of the area but I didn't understand the thickness.

DR. CASHMAN: The thickness is such that the layer is about opaque.

DR. KELLOGG: Very thin?

DR. CASHMAN: Yes.

DR. KELLOGG: I believe you said something about the name of the company that could supply it.

DR. CASHMAN: I said that some of these types are made by the Electro-Voice Corporation in Chicago. Several other concerns are setting up manufacturing facilities to make the cell.

MR. MORELOCK: Did I understand you to say that the exciter lamp is also commercially available?

DR. CASHMAN: It is still being experimented with and it is not yet available.

MR. GREEN: You made some comment with respect to the signal-to-noise ratio. Do I interpret it to mean that in running a variable-area track, which is approximately half clear and half opaque, the lead-sulfide cell will be quieter?

DR. CASHMAN: Yes, because the noise does not go up with the background—it goes down.

MR. W. S. MARTIN: What about the life of these cells in comparison with the old cells?

DR. CASHMAN: It is hard to say. We haven't had them long enough. Some have been in use since 1944. They are still just as good as when they were made.

MR. MARTIN: Can the sensitivity of this cell be controlled very accurately?

DR. CASHMAN: You mean in manufacture?

MR. MARTIN: Yes.

DR. CASHMAN: The cell characteristics can be controlled quite accurately.

MR. MARTIN: Have you done any experimenting with inserting a reflector to reflect the light after it passes through the film into the photocell instead of going direct from the exciter lamp after it passes through the film?

DR. CASHMAN: I haven't, but I believe Mr. Van Niman has.

MR. R. T. VAN NIMAN: We have used both lenses and mirrors.

MR. E. I. SPONABLE: It might interest the membership to know that I spent about ten years on photoactive materials that change resistance on exposure to light. So far as I know, we at the Case Research Laboratory discovered the photoactivity of lead sulfide, antimony sulfide, and thallous sulfide. Back in 1918 I remember that we were able to detect a man smoking a cigar a mile away. We thought that quite an achievement at the time. We also talked over a light beam a distance of some eight or ten miles. I am glad to hear that this interesting material has been rediscovered.

DR. CASHMAN: If I recall correctly, in your experiments, you used 60-inch mirrors or something like that.

I was instructed by the program committee to avoid historical surveys of this subject in order to save time. The pioneer work of the Case Research Laboratory, with which Mr. Sponable was connected, deserves the highest praise for its exploratory work in this field. The laboratory is best known for its development of photosensitive thallous sulfide. The cells made with their material were not stable, however. This defect has been overcome in the modern thallous-sulfide cells. The Case laboratory also observed photosensitivity in natural lead sulfide (Galena) but this observation had been reported several times previously by other investigators, for instance, Mercadier, U. S. Patent 420,884 (1890). The present lead-sulfide cell contains an activated synthetic preparation of lead sulfide.

MAGNETIC SOUND FOR 8-MM PROJECTION*

MARVIN CAMRAS**

Summary.—*A magnetic track deposited between the sprocket holes and the edge of 8-mm film gives good-quality sound which can be added to any ordinary 8-mm film. Modifications of standard projectors for using this system are described. Performances for speeds of 16, 18, and 24 frames per second are given.*

Although sound on 8-mm film has been considered in the past, results were discouraging, and up to the present time no 8-mm sound projector has appeared on the market.† One difficulty with 8-mm films is the limited space available for a sound track. Fig. 1 shows the relative dimensions of standard films. The 35-mm film has a track about 100 mils wide; on 16-mm film it is about 80 mils wide. With 8-mm film the maximum track width is only about 30 mils. This track can be located at the film edge, either on the sprocketed side *A* or on the picture side *B*.

PROBLEMS WITH OPTICAL METHODS

More serious than the reduction in track width is the low 8-mm film speed. Table 1 compares the room available for storage of

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* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Armour Research Foundation, Chicago 16, Ill.

† Apparatus using a separate disk phonograph is available.

35-, 16-, and 8-mm sound. A 35-mm sound film running at 24 frames per second, goes through the soundhead at 18 inches per second, and the track is 100 mils wide. If we multiply the film speed by the track width we get a sound-storage index number of 1800. The 16-mm sound on the same basis has an index number of 567, or roughly 31 per cent as much. When we get to 8-mm film the index has dropped to 6 per cent for a 24-frame speed, and to only 4 per cent at a 16-frame speed. Experience shows that in going from 35-mm to 16-mm sound

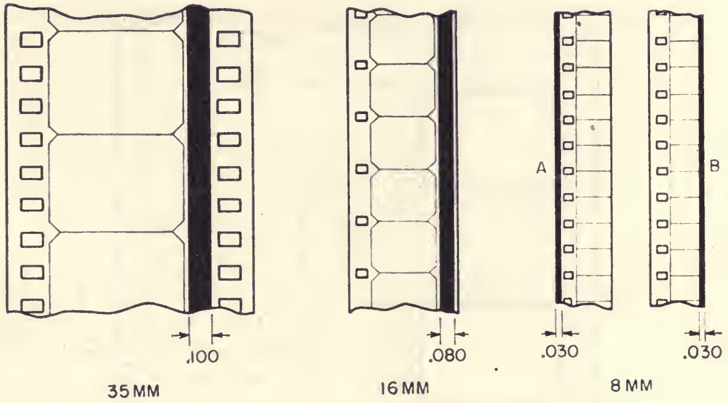

FIG. 1. Relative sound-track dimensions.

there is marked deterioration in quality. Considering that 16-mm sound with a rating of 31 per cent is not too far above the borderline for high-quality sound, the possibilities for 8-mm with a 4 per cent to 6 per cent rating seem discouraging.

TABLE 1

Sound Storage Index for Films

Type of Projection	Frames per Second	Film Speed, Inches per Second	Track Width, Mils	Sound Storage Index = Speed × Width	Relative Per Cent Rating
35-mm sound	24	18	100	1800	100
16-mm sound	24	7.2	80	576	31
8-mm sound	24	3.6	30	108	6
8-mm silent (1)	18	2.7	30	81	$4^1/_2$
8-mm silent (2)	16	2.4	30	72	4

If we choose to put the 8-mm sound track on the picture side, then we reduce the already limited picture area. Projectors would have to be modified for the smaller picture size. The possibility of adding tracks to old films would also be limited. We can avoid these difficulties by locating the track on the sprocketed side. If we try optical sound there are photographic troubles which are indicated in Fig. 2. Frayne and Pagliarulo[1] have shown that film processing may cause uneven development of images that are as much as 30 mils from the sprocket holes. The uneven action of the developer at the edges

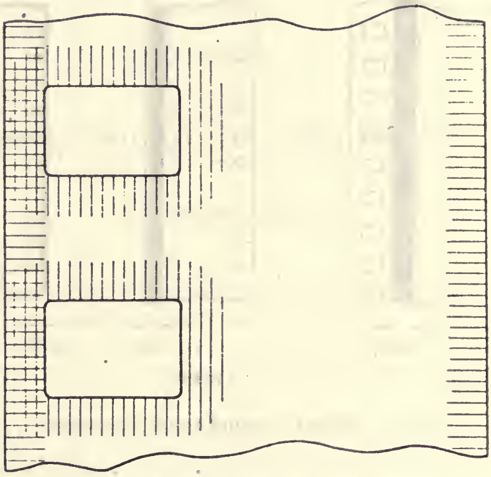

FIG. 2. Region of uneven development.

of the sprocket holes has been represented by vertical shading. There is also the possibility of action at the film edges, and this has been indicated by horizontal shading. Uneven development of this kind can cause sprocket-hole modulation even when the drive system is perfect.

Economic problems also must be considered. Eight-millimeter photography has sacrificed quality in order to give the lowest possible cost. If sound can be provided only by critical and expensive equipment and processes, the average amateur will not be able to afford it.

MAGNETIC METHOD

Magnetic recording offers a fresh approach to the problem of sound for 8-mm projection.[2] Instead of an optical track of varying density

or area, a layer of a newly developed magnetic material is bonded to the film in the space between the sprocket holes and film edge. This magnetic material has high coercive force and remanence, so that it may be magnetized in accordance with variations of magnetic flux in the $^1/_2$-mil gap of a recording head that rides against it.

Fig. 3 shows one method for accomplishing this. With the selector switch in the record position shown, acoustic waves picked up by the microphone are amplified and fed into the magnetic head. Here they are changed into magnetic-flux variations which are recorded on the magnetic film track. The same head is used to translate the magnetic record back into electrical energy. With the switch in playback

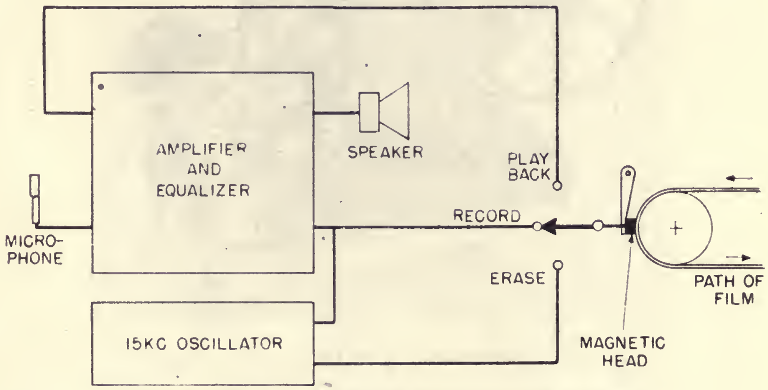

FIG. 3. Magnetic sound-on-film recording system.

position, these waves are amplified and fed into a loudspeaker. Although the record is "permanent" and will last for the life of the film, it may be erased quite readily by switching to the erase position and running a high-frequency alternating-current demagnetizing flux through the head.

It is apparent that magnetic sound has a number of special advantages for the amateur:

(1) Recordings can be made in the home, without special equipment.

(2) They can be played back immediately without processing.

(3) Records may be erased and rerecorded.

(4) Old films can be adapted for sound by adding a track.

(5) Present silent equipment can be converted for sound.

A HIGH-QUALITY 8-MM SOUND PROJECTOR

To demonstrate the possibilities of 8-mm systems, some conventional 8-mm projectors were converted for sound. Fig. 4 is a photo-

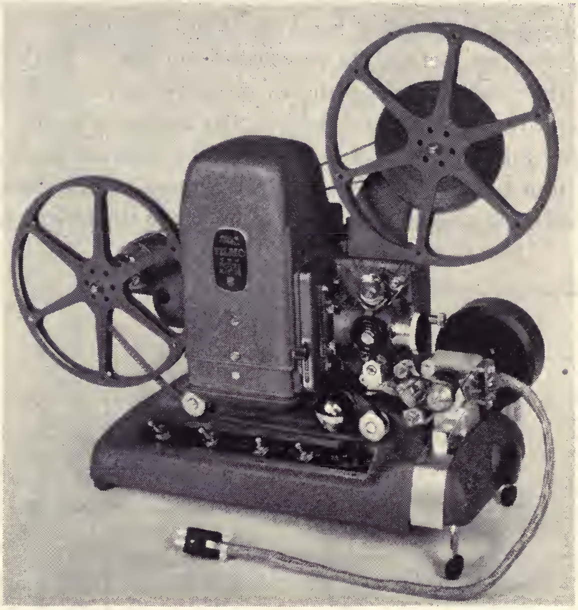

FIG. 4. Eight-millimeter magnetic sound projector.

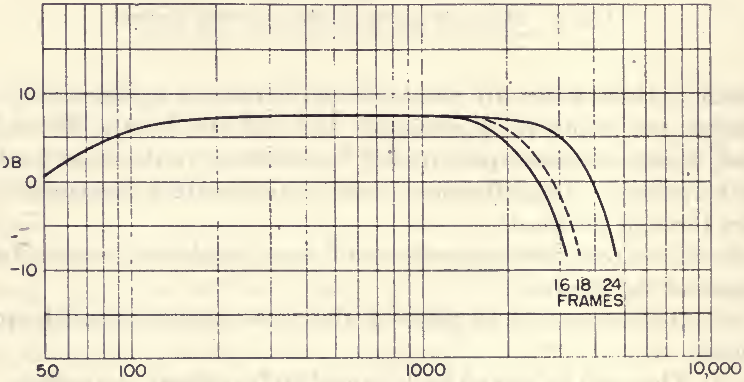

FIG. 5. Over-all response of 8-mm system.

graph of the equipment that you now hear. A flywheel and damper arms were added to the silent projector, This gives essentially the

same mechanical system used by the company on its 16-mm sound equipment. It should be noted that if a 16-mm flywheel system is used on 8-mm, the energy storage is reduced to only 25 per cent, since the energy varies as the square of the velocity. A corresponding increase in flutter and "wow" should be expected, unless it is corrected by improved mechanical design.

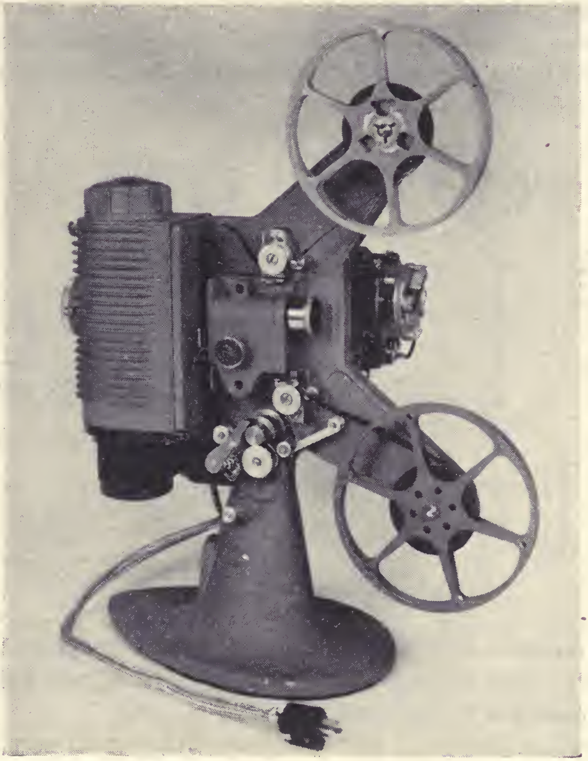

FIG. 6. Converted 8-mm silent projector.

Of the projection speeds there are three possibilities to choose from: 24, 18, or 16 frames per second. Eight-millimeter sound films which are made from 35- or 16-mm originals will most conveniently use 24-frame projection. Best fidelity is offered by this speed. On the other hand, old silent films which have a track added should be run at their original 16-frame speed. It has been found by experience

that most amateurs project their silent films at about 18 frames per second, since this "livens up" the action. Data for the 18-frame speed accordingly have been taken. On new productions intended for magnetic sound the amateur will have his choice of the higher fidelity 24-frame speed, or the more economical 18-frame speed (provided his camera can be set at either one). Frequency-response curves for the various speeds are given in Fig. 5. While not "high fidelity" the response compares with that of super-heterodyne radio receivers. Listeners have commented that both speech and music are excellent. It is interesting to note that in tests

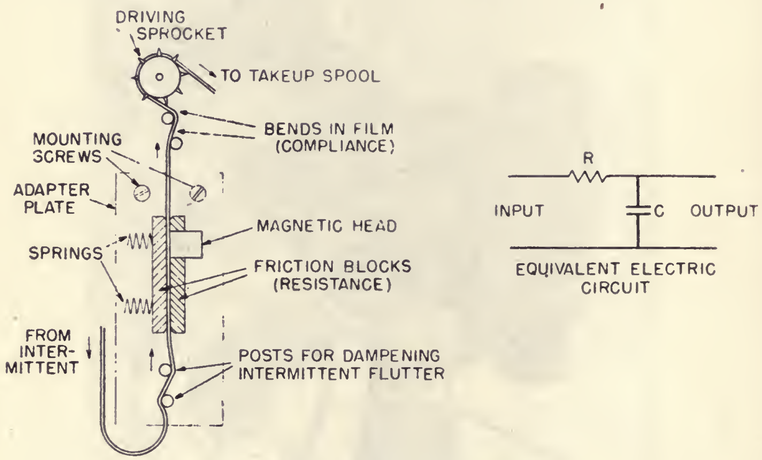

FIG. 7. Adapter for 8-mm projectors.

we have recorded as high as 10 kilocycles with a $2^1/_2$-inch-per-second film speed. This is not typical, of course, but it does indicate that there is room for future improvement.

The present converted unit is not operating at its best because it uses an unregulated series motor. The addition of a governor, or the use of an alternating-current motor would decrease "wow" considerably. Another standard projector which has been converted is shown in Fig. 6.

A SIMPLE ADAPTER UNIT FOR 8-MM PROJECTORS

An attempt was made to design the simplest possible 8-mm sound adapter unit which could be applied to 8-mm projectors. One of the designs evolved is shown in Fig. 7. All of the essential parts are

fastened to a plate which may be mounted on the projector with a pair of screws. The film comes down from the optical gate, and loops up past a pair of posts which take out most of the intermittent flutter. It then is pulled through a pair of friction shoes into the sound gate. The magnetic head is mounted in a recess in the stationary shoe. Its high impedance of 9000 ohms at 1000 cycles allows

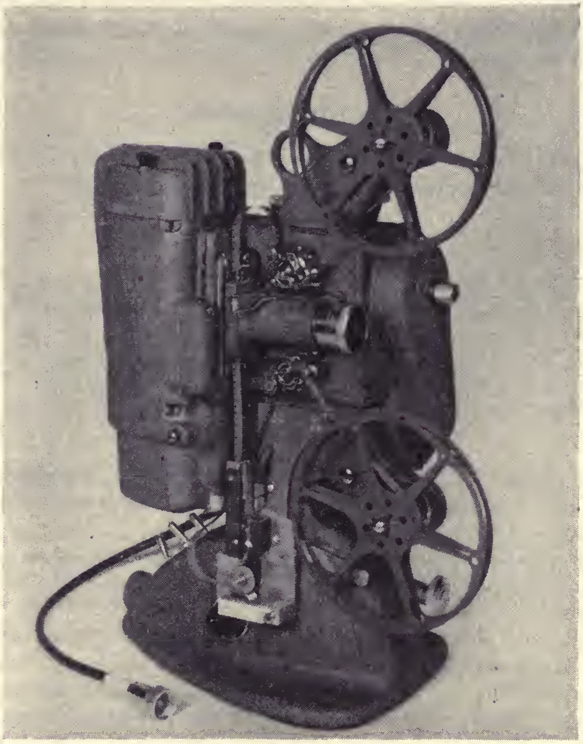

FIG. 8. Adapter plate mounted on 8-mm projector.

it to operate directly into the amplifier grid. A pair of posts between the drive sprocket and the friction shoes bend the film to provide compliance. All posts and shoes are grooved so they cannot scratch the picture portion of the film. The film compliance and friction blocks form a simple resistance-capacitance-type filter indicated by the electrical-filter circuit at the right.

The adapter unit, mounted on a typical 8-mm projector, is shown in Fig. 8. The demonstration model operates under unfavorable conditions. It uses a series-type universal motor with poor regulation and V-belt coupling. Sprockets are driven by gears, and are of small diameter (12-tooth). The intermittent mechanism gives a fluctuating load on the poorly regulated motor. In spite of these faults (many of which could be corrected in a machine designed for sound adaptation) the projector does a creditable job for voice work, and gives quality that should be acceptable for such things as amateur titling and narrative.

ACKNOWLEDGMENT

The author wishes to thank Ampro, Bell and Howell, and Univex for generously supplying equipment used in these tests.

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DISCUSSION

MR. WILLIAM KRUSE: At what speed was the recorded talk played?

MR. MARVIN CAMRAS: The voice was run at 24 frames and the music at 18 frames, which is close to silent speed.

MR. O. B. DEPUE: How do you apply the magnetic material on the film?

MR. CAMRAS: The coating is in a liquid form and is flowed onto the film and is bonded into it.

DR. E. W. KELLOGG: Have you done all of your applications of the coating material or is any commercial concern preparing that film?

MR. CAMRAS: This has been done at the Armour Research laboratory.

MR. KRUSE: What progress is being made toward commercializing the coating process? It seems that is the keynote to the usefulness of the whole thing.

MR. CAMRAS: You have to have both things simultaneously. You have to have projectors that will use the film and you have to have the film. The laboratories that coat the film will want the market for it, and those who make the projectors will want the film available. We hope that within a few months there will be some of this film available commercially and possibly some experimental equipment to use it.

SYNCHRONIZED 16-MM SOUND AND PICTURE FOR PROJECTION AT 16 FRAMES PER SECOND*

GEORGE E. H. HANSON**

Summary—*This paper describes a method of re-recording 35-mm sound track to obtain a 16-mm track, which will reproduce synchronously with a 16-mm picture projected at 16 frames per second. The only necessary modification of a standard re-recording channel to perform this operation is the substitution of an 1800-revolution-per-minute synchronous motor for the standard 1200-revolution-per-minute motor on one 35-mm soundhead.*

Before the advent of sound recording on film and the establishment of 24 frames per second or 90 feet per minute as the standard of film speed in motion picture cameras and in sound-on-film recording machines, many millions of feet of 35-mm motion pictures were photographed at the film speed of 16 frames per second. Also, in the field of 16-mm amateur photography, practically all shooting has been and still is done at 16 frames per second.

As is well known, in order to obtain a faithful pictorial representation of the action photographed, the picture must be projected at the sa e speed as that at which the action was photographed. In other words, action photographed at 24 frames per second must be projected at 24 frames per second, and action photographed at 16 frames per second must be projected at 16 frames per second.

The problem has frequently occurred of adding synchronized music, sound effects, and commentary to these silent films shot at 16 frames per second, and the question arises as to what is the most satisfactory and economical way of doing this without serious and expensive modification of the standard recording system designed to operate at a speed of 24 frames per second.

First, let us consider the 35-mm films. Here we are faced with the condition that all 35-mm projection equipments, designed for sound reproduction, run at the standard projection speed of 24 frames per second. This leaves us, therefore, with only one obvious solution to the problem. In order to maintain the illusion of normal movement on the screen, it becomes necessary to double-print every other frame of picture and thus convert the 16-frame shooting speed into the equivalent of 24-frame shooting speed.

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* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Warner Brothers Pictures, Inc., Burbank, Calif.

The net result of this correction is normal speed of motion on the screen, but with an obvious lack of smoothness in the action. However, the slight jerkiness that appears is much less objectionable than the ludicrous effect of all movement being one half faster than normal, as is the case when a picture shot at 16 frames per second is projected at 24 frames per second. After this pictorial correction is made, the recording of music, sound effects, and speech can then be added in the normal manner as is done with any standard 35-mm picture shot at the 24-frame-per-second speed. No changes in recording equipment or techniques are necessary.

In the case of 16-mm films, however, the problem allows for other solutions because most sound-and-picture 16-mm projection machines are designed to run at *either* 16 or 24 frames per second. The problem could be solved by double-printing every other picture frame as in the 35-mm case, but since we have a 16-frame projection speed available, some scheme that avoids mutilation of the picture is much more desirable. One obvious way to do this would be to modify the sound-recording equipment to run at 16 frames per second. There are two serious objections to doing this. First, such a modification would temporarily put a standard recording channel out of commission for normal recording and this, of course, would be prohibitively expensive in a commercial recording plant. Second, such a reduction in running speed would seriously affect the functioning of mechanical filtering devices designed to produce smooth film motion at the correct 90-feet-per-minute operating speed of the recording and reproducing equipment. The following scheme is presented, therefore, as being the most satisfactory and economical solution of producing sound-on-film records which can be reproduced at 16 frames per second in a 16-mm projector.

Let us assume that we are to add a combination of music, sound effects, and commentary to a 16-mm picture and that the final combined sound and picture print is to run at 16 frames per second. Also, assume that the commentary is to be recorded originally for the 16-mm picture and that the music and effects tracks are to be compiled from a stock 35-mm sound library.

The procedure is as follows: The commentary is recorded on a standard 35-mm recorder, running at 90 feet per minute, while the commentator views the picture which is projected at 16 frames per second, using an interlock motor drive suitably geared to the projector. The music and sound-effects tracks are compiled in the usual

manner from footage measurements, allowing $3^3/_4$ feet of 35-mm track for each foot of 16-mm picture. (Appendix A explains how this ratio is determined.) These tracks are then combined into a single 35-mm track by standard re-recording or dubbing methods.

The resulting 35-mm dubbed track is then reproduced on a soundhead driven at 50 per cent above normal speed. This is accomplished by substituting an 1800-revolution-per-minute synchronous motor for the usual 1200-revolution-per-minute driver. By this operation, a frequency say of 6000 cycles in the recording is raised to 9000 cycles and the total playing time of the recording is two thirds of normal. This speeded-up sound track is then re-recorded on a 16-mm recording machine running at the standard 24-frame-per-second speed. During this re-recording operation, it is, of course, necessary to remove the usual 7000- or 8000-cycle low-pass filter from the re-recording channel, in order to pass the higher-frequency band being reproduced under this speeded-up condition. We now have a 16-mm version of our original recording which, if reproduced at the standard 24-frame speed, would be one-half octave too high in pitch and two thirds of the normal length in playing time. Now, if we reproduce this 16-mm sound track on a 16-mm reproducer, running at 16 frames per second, the playing time and pitch are restored to normal and we have accomplished our objective. As can be seen, the only modification that has been made to either the standard 35- or 16-mm recording equipment has been to equip one 35-mm soundhead with an 1800-revolution-per-minute driving motor, the remainder of the plant being left intact for standard recording procedures.

In order to study the effect of this type of re-recording operation on the frequency characteristic of the recorded material, the following test was performed. A 35-mm frequency test film having a constant percentage modulation for each frequency was first reproduced at the standard sound speed of 90 feet per minute through a re-recording channel having normal film-loss compensation. The substantially flat output from this film was fed to a 16-mm recorder running at sound speed and a 16-mm re-recording of the frequency film was made. The output from the 16-mm film was then measured on a Bell and Howell 16-mm sound projector with the tone controls adjusted for optimum frequency response. The characteristic obtained is shown in curve, (A) Fig. 1.

The same 35-mm frequency film was then reproduced on a soundhead running at 50 per cent overspeed and the output was fed through

the same re-recording channel to the 16-mm recorder running at standard speed. The 16-mm re-recording thus obtained was then reproduced on the Bell and Howell projector, with the same tone-control settings, but running at the silent speed of 16 frames per second. The output of this film was measured and the characteristic obtained is shown in curve (*B*), Fig. 1.

As is to be expected, the 50 per cent overspeed recording results in a slight increase in film loss at the higher frequencies, while virtually no change takes place in the low-frequency response. Compensation

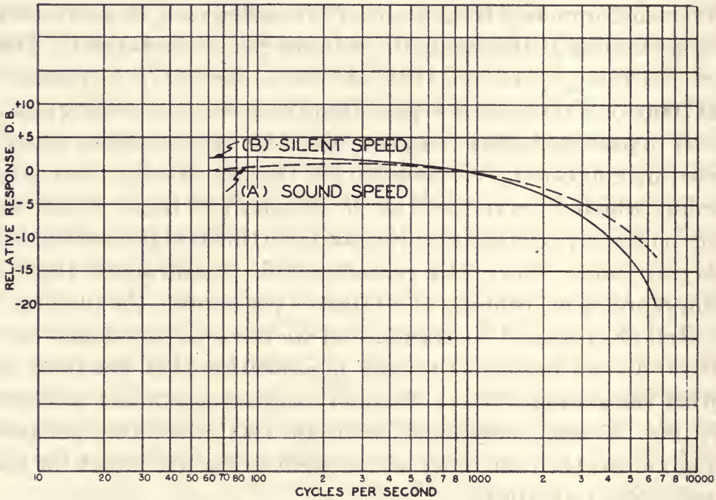

FIG. 1. Relative response of 16-mm sound track re-recorded from 35-mm sound track. (*A*) 35-mm sound track and 16-mm sound track both reproduced at standard sound speed (24) frames per second. (*B*) 35-mm track played 50 per cent over speed and 16-mm track reproduced at silent speed (16) frames per second.

for the high-frequency loss (6 decibels at 6000 cycles) can be provided for easily in the re-recording channel, but it is felt that for most commercial applications this compensation could be disregarded since the amount of equalization required comes well within the tone-control range of the average 16-mm sound projector and could be applied there.

Actual commercial recordings produced in this manner substantiate this point and have demonstrated the highly satisfactory results that can be obtained by using the method described herein for adding sound to 16-mm pictures photographed and reproduced 16 frames per

second with a minimum of modification to a standard recording and re-recording plant.

APPENDIX A

One foot of 16-mm picture has 40 frames. If this picture is projected at 16 frames per second, the length of film passing through the projector per second is $16/40 = {}^2/_5$ foot. The standard projection speed of 35-mm film is 90 feet per minute or $1^1/_2$ feet per second. Therefore, the ratio of the length of 35-mm film projected at 90 feet per minute, to the length of 16-mm film projected at 16 frames per second, for equal projection times, is 1.5/0.4 or 3.75.

THE OPTIMUM WIDTH OF ILLUMINATION OF THE SOUND TRACK IN SOUND-REPRODUCING OPTICS

JOSEPH C. FROMMER*

When deciding on the width in direction of film travel of the illuminated area on the sound track ("scanning width"), a compromise has to be found between two contradictory requirements: more scanning width allows the passage of more light and gives a proportionally higher signal level for low frequencies, but it will cause an increased fall off at higher frequencies, where the scanning width covers an appreciable portion of one wave. Accordingly there exists for each frequency a scanning width with which the signal output is highest.

If the photoelectric amplifier is designed to provide sufficient amplification for the highest frequency recorded, then the amplification for lower frequencies will be more than sufficient. Flat response can then be obtained by attenuating these lower frequencies. Consequently, when deciding on the scanning width, we must consider only the highest required frequency.

If we designate the reproducing scanning width by r, the frequency by f, the film travel speed by v, then the output signal will be proportional to[1]

$$\frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v} r}. \qquad (1)$$

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But the signal output is also proportional to the light flux in the scanned area, which in turn is proportional to the scanning width, so that the signal level at the frequency f will be proportional to

$$r \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v} r} = \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}}. \tag{2}$$

To find the maximum of this expression, form the derivative

$$\frac{d}{dr} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}} = \cos \frac{\pi f}{v} r. \tag{3}$$

This derivative will equal zero where

$$\frac{\pi f}{v} r = \frac{\pi}{2} \tag{4}$$

or

$$r = 0.5\, v/f. \tag{5}$$

Maximum output for the frequency f will be obtained at this scanning width.

Numerical example: for a film travel speed of 36 feet per minute (7.2 inches per second) and for reproduction desired up to 6000 cycles per second, the scanning width optimum for highest signal input is

$$0.5\, v/f = 0.5 \times 7.2/6000 = 0.0006 \text{ inch}.$$

A high photoelectric signal level is desirable mainly because it requires less amplification and accordingly that part of the background noise at the amplifier input, which is independent of the photoelectric signal, will be less amplified, or in other words, the signal-to-noise ratio will improve. That part of the background noise however, which is caused by thermal agitation in the photoelectric tube, is not independent of the photoelectric signal level, inasmuch as with increasing scanning width the average photoelectric current will increase and the thermal noise of the photoelectric tube will increase with the square root of this increased current.[2] Therefore in applications in which the main concern is to improve the ratio between signal and the noise caused by thermal agitation in the photoelectric tube ("*PE* noise"), the optimum scanning width is the one at which the ratio between the photoelectric signal and the square root of the average photoelectric current is highest.

The photoelectric signal is proportional to Eq (*2*), the average photoelectric current is proportional to the scanning width r, its square root to $\sqrt{r}$, consequently the ratio between photoelectric signal and square root of average photoelectric current is proportional to

$$\frac{r}{\sqrt{r}} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v} r} = r^{-1/2} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}}. \tag{6}$$

The first derivative of this expression is

$$\frac{d}{dr} r^{-1/2} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}} = -{}^1/_2 r^{-3/2} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}} + r^{-1/2} \cos \frac{\pi f}{v} r \tag{7}$$

which becomes zero where

$$^1/_2 r^{-3/2} \frac{\sin \frac{\pi f}{v} r}{\frac{\pi f}{v}} = r^{-1/2} \cos \frac{\pi f}{v} r \tag{8}$$

or

$$\frac{\pi f}{v} r = {}^1/_2 \tan \frac{\pi f}{v} r. \tag{9}$$

This equation is satisfied by

$$\frac{\pi f}{v} r = 1.165 \tag{10}$$

because tan 1.165 = 2.33 = 2 × 1.165, whence

$$r = \frac{1.165}{\pi} \frac{v}{f} = 0.37v/f \tag{11}$$

will give the highest *PE*-signal-to-*PE*-noise ratio.

Numerical example: For a film travel speed of 36 feet per minute (7.2 inches per second) and for reproduction desired up to 6000 cycles per second, the optimum scanning width for highest *PE*-signal-to-*PE*-noise ratio is

$$0.37v/f = 0.37 \times 7.2/6000 = 0.00044 \text{ inch.}$$

The actual background noise contains both *PE* noise and noise independent of the *PE* current. Accordingly the best scanning width is somewhere between 0.37 v/f and 0.5 v/f calculated for these two types of noise.

The calculations in this paper were based on the assumption of constant light flux per illuminated area. In a further step this assumption has been dropped and the opening of the aperture stop has been taken as another variable. Publication of these more involved calculations however must be delayed till after publication of the underlying optical investigations.

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[2] V. K. ZWORYKIN AND G. A. MORTON: "Television", John Wiley and Sons, New York, N. Y., 1940, p. 13, Eq 11.1.

A PHOTOELECTRIC FILM CUING SYSTEM*

IRWIN A. MOON**

Summary—*A photoelectrically operated cuing system has been developed which avoids the difficulties associated with lack of standardization on edge-notching of film, increases the ease of changing the cuing marks, and also makes feasible concurrent cuing of both light change and special effects. This system has been applied successfully to a standard Bell and Howell Model* J *printer. However, the features discussed are general and applicable to any type of film-moving system. Spots of white lacquer between the sprocket holes are illuminated by a small beam of light. The reflected light causes a discontinuity in the photoelectric-tube current which is amplified to operate a relay. The printer exposure channel actuates the normal light-change solenoid while the relay in the effect channel is used to initiate fade-in, fade-out cycles through the medium of a magnetic clutch which engages a rheostat in the lamp circuit. Practical operating experience and detailed mechanical features are described.*

INTRODUCTION

The introduction of printer effects and the desirability of varying filter combinations during the printing operation have placed new and unusual demands upon the already inadequate method of printer cuing by edge-notching of the printer negative. The limitations, the lack of standardization, and the irrevocably permanent nature of the edge notch present very real problems. In some laboratories these problems are overcome by the use of a separate cuing film or tape. The preparation of this tape is often a costly and time-consuming process and its use is accompanied by added storage and filing problems and introduces one more possibility for error in an already complex operation.

Obviously, a dependable system of multiple-channel cuing which could be applied directly to the printer negative without damage to the film and which could be removed or altered with ease is greatly to be desired. The Moody Institute of Science has developed and is currently using a system of photoelectric cuing for printing 16-mm films that gives promise of meeting these demands. A standard Bell and Howell Model *J* printer equipped wlth such a photoelectric cuing system is shown in Fig. 1.

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* Presented Apr. 22, 1947, at the SMPE Convention in Chicago.

** Director, Moody Institute of Science, Los Angeles, Calif.

GENERAL DESCRIPTION

In brief, this system utilizes for the cuing marks spots of white lacquer or other highly reflecting material approximating the size of a sprocket hole and applied midway between the sprocket holes of the printer negative as shown in Fig. 2. The pulse generated by a photoelectric tube as this spot passes a scanning aperture is amplified

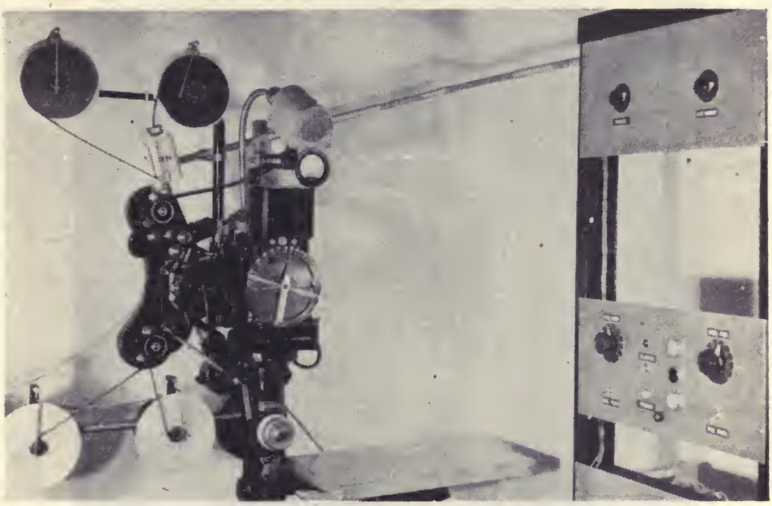

FIG. 1. Photoelectric cuing system installed on Model *J* Bell and Howell printer.

and used to operate a relay which initiates the desired function. By scanning both edges of the film, along the sprocket holes, two functions may be initiated in a simple manner. By applying somewhat more complex electronic selection circuits it is possible to initiate more than one function on each channel by the use of single marks, double marks, and so on. The positioning and shaping of the cuing marks are not critical. Satisfactory results have been obtained with marks applied with a small brush. In any extensive use of such a system, however, the use of the more highly refined blooping techniques in applying the cuing marks would be desirable.

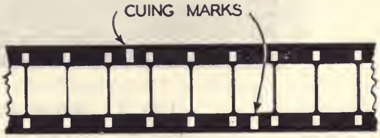

FIG. 2. Placement of white cuing spots on 16-mm original film.

SCANNING HEAD

The position of the scanning head on the printer is shown in the photographs of Figs. 1 and 3. In the latter figure the gate is open revealing the two scanning apertures between the film-bearing surfaces. Fig. 4 shows the scanning head with the film threaded ready for use.

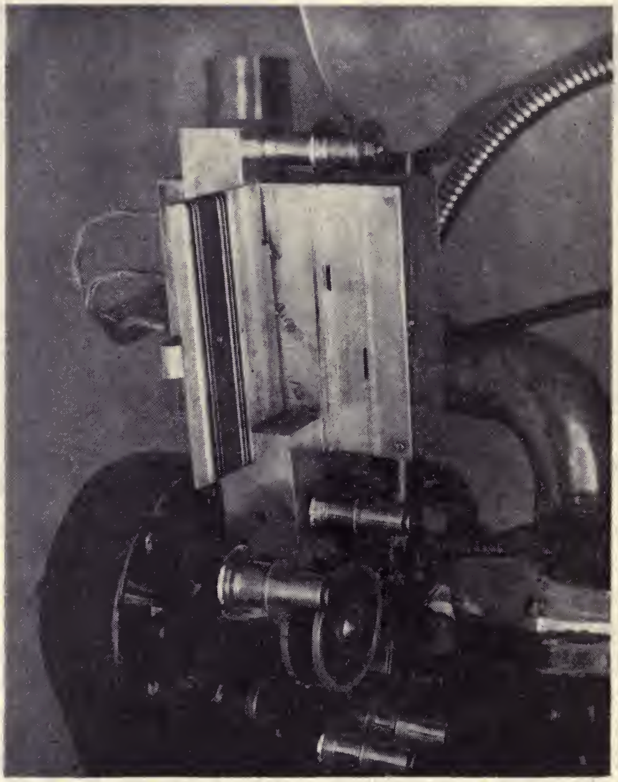

FIG. 3. Scanning head with cover open.

The drawing in Fig. 5 shows the details of the photoelectric scanning head. The light from a small flashlight bulb of the type having the lens molded into the envelope illuminates the film and the reflected light falls upon a photoelectric cell. As a spot passes the scanning aperture, a short pulse of photoelectric current results due to the greater reflectivity of the white spot. The geometrical

arrangement is such that the light falling upon the photoelectric tube is that caused by diffuse, rather than specular, reflection, resulting in a more favorable signal-to-noise ratio. The signal-to-noise ratio of the system is established at this point, the background noise being essentially that due to modulation of the light by the sprocket holes.

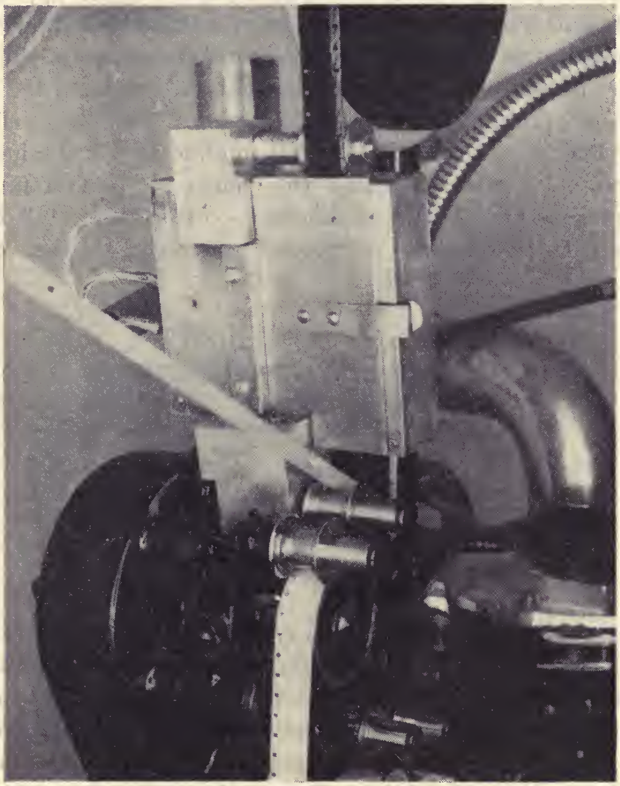

FIG. 4. Scanning head threaded and cover in place.

This sprocket-hole modulation is minimized by blackening the areas of the backing plate behind the sprocket holes. Wear on the film as it passes through the scanning head is minimized by careful polishing of the bearing surfaces, but whatever wear results takes place outside of the picture area.

AMPLIFIERS

The pulse from the photoelectric-tube circuit is led to a conventional resistance-capacitance-coupled amplifier consisting of four

stages, utilizing three type *6SJ7* tubes with a type *6V6* output stage. This output stage is transformer-coupled to a 500-ohm line terminating in a conventional alternating-current relay. Feedback loops around the first two and also the last two stages stabilize the operation of the amplifier.

For a film speed of 60 feet per minute, a spot width of approximately 0.1 inch, and a scanning aperture approximately the size of the spot, the photoelectric pulse has a fundamental frequency of the order of 60 cycles per second. The wave shape at the output of the amplifier is a single cycle of almost true sine shape. The time constants of the amplifier are adjusted so that full amplification is obtained at this frequency. In order to reduce the chance of the system responding to spurious signals, the amplifier response is made to fall off rapidly above and below 60 cycles per second. Reducing the high-frequency

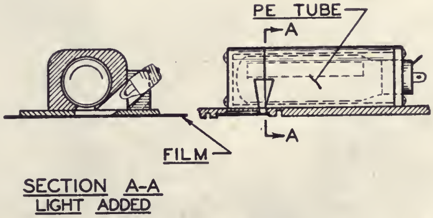

FIG. 5. Drawings of scanning head.

response eliminated trouble from tripping by transient electromagnetic fields set up when the light-change solenoid was operated. Some instability was experienced until an electronically regulated power supply was used for the amplifiers. With this highly regulated supply, very dependable and reproducible operating characteristics were obtained. It completely eliminated spurious operations of the relay resulting from power-line surges.

APPLICATION TO PRINTER LIGHT CHANGE

A photoelectric cuing system as described could quite obviously be used to initiate many different functions pertinent to the printing process. For example, one of the simplest applications is that of controlling the light-change device of a standard printer. A schematic diagram of this is shown in the upper portion of Fig. 6. In this case the contacts of the relay controlled by the signal are connected

in parallel with the contactor normally actuated by the edge notch on the film. Aside from the fact that the initiating signal comes from the photoelectric channel rather than the edge-notch contactor, the operation of the printer is entirely normal. As the signal duration, and hence the relay-closing time, at the output of the amplifier is of the order of a sixtieth of a second, this would apply only about one cycle of alternating-current power to the light-change solenoid. For positive operation it was found necessary to extend this time some-

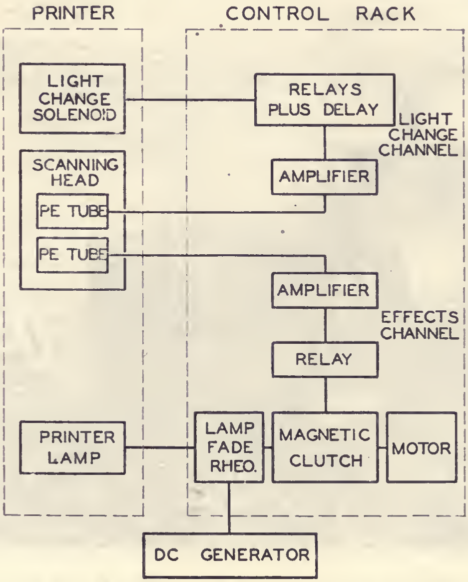

FIG. 6. Operational diagram of cuing system.

what by the addition of a supplementary direct-current relay having a capacitor across its actuating coil.

APPLICATION TO PRINTER EFFECTS

The introduction of printer effects, such as fades and dissolves is another application of the photoelectric cuing system. Although the printer fade in this laboratory is now being achieved by lamp-voltage variation (a method which leaves something to be desired) the device is equally adaptable to other methods than the one herewith described. A schematic diagram of the effects channel is shown in the lower part of Fig. 6.

In the effects channel, the heart of the control lies in a magnetic clutch. After the initiation of the operation, a mechanico-electrical interlock completes the cycle. To assure positive start and stop, and to make possible precise timing of the cycle regardless of starting and stopping inertia factors, the drive motor is operated continuously and is coupled to the controlled function by means of a magnetic clutch. Such a clutch, quite simple in design and construction, has been found to engage and release very positively and, for all practical purposes, instantaneously.

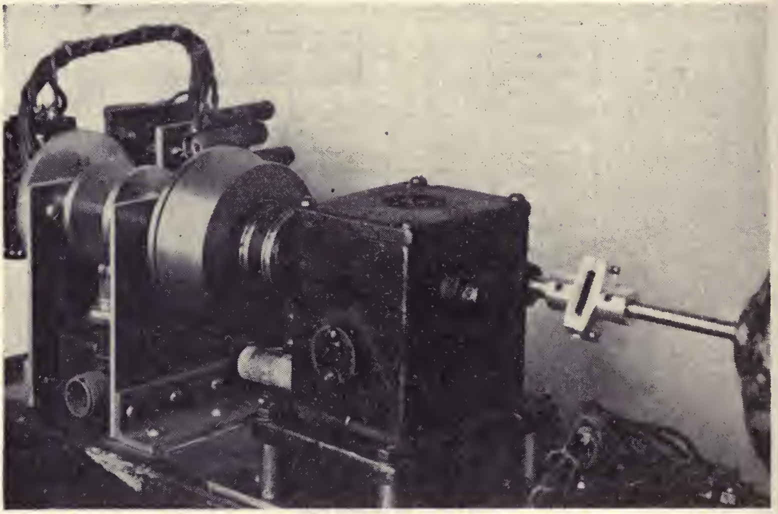

FIG. 7. Magnetic clutch chassis with motor-driven fader rheostat.

As shown in Fig. 7, a motor is coupled to a printer lamp fader rheostat through the medium of this magnetic clutch. The constructional details of the clutch are shown in the drawing of Fig. 8. The operation of this interlock system is as follows: the amplified photoelectric pulse actuates a relay which closes a local circuit energizing the magnetic-clutch coil. The motor is thus coupled to the shaft rotating it, and a cam-operated switch holds this clutch circuit closed once it has been initiated by the photoelectric pulse. At the completion of the fade-in or fade-out cycle, represented by a half turn of this shaft, the cam-operated relay opens the clutch circuit. The next pulse would then complete the cycle, bringing the rheostat back to its

original position. The cam-operated relay is necessary to keep the magnetic clutch closed beyond the brief duration of the original initiating photoelectric pulse.

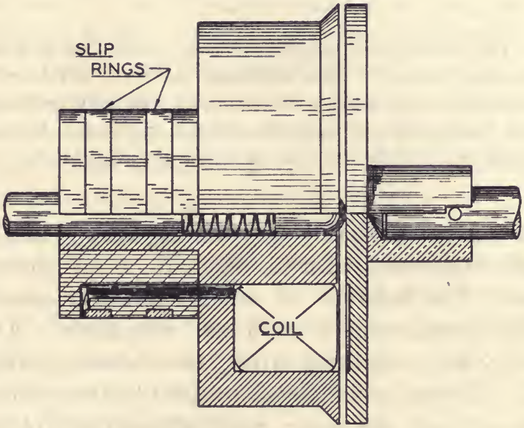

FIG. 8. Sketch of magnetic-clutch details.

The design of the fader rheostat is complicated by many dynamic factors such as persistence of vision, thermal inertia of the lamp filament, and change of printer lamp resistance with temperature. A satisfactorily smooth approximation to an ideal straight-line curve (in terms of the change of density with time as viewed on the projected film) has been made, utilizing 16 resistance increments per fade cycle for Kodachrome duplication.

SPACE ACOUSTICS*

JAMES Y. DUNBAR**

Summary—*The relationship between the area, shape, and fitments of a sound studio or auditorium and their effect on sound quality is discussed. A probable evolution of music appreciation, from the pentatonic and whole-note scales of certain primitive peoples to harmony, as we know it today, is traced. Various methods of acoustical treatment of enclosed areas are described and illustrated.*

Sound is a form of pulsating or vibrating energy and in this discussion we are concerned with its behavior in an enclosure or restricted space. The behavior of sound energy in space, be it in a theater, studio, living room or bathroom, is acoustics. The source of the sounds may be a vibrating string, membrane, column of air, or vocal chords. The air as a medium coupled to the source carries the vibration throughout the space until attenuated by distance, or absorbed by boundary surfaces.

Sustained sounds thus will fill a space and the intensity will grow by the addition of the various reflections until that steady state is reached when the energy of the source is balanced by the boundary loss, or absorption. If the source is suddenly stopped the residual sounds continue to reflect and to die away because of absorption.

The time taken for the sound level to drop 60 decibels is called the reverberation time. Some modern structures with hard surfaces have been known to have reverberation times in excess of 10 seconds. When we consider that we normally speak about three syllables per second and this extreme would mean thirty syllables running around the hall at the same time, we see what utter confusion and unintelligibility can result from excessive reverberation. Music in the same place would sound as though the loud pedal were on all of the time.

It is probable that the growth of modern music and our appreciation of it have been molded by the architecture of our buildings. The music of most primitive civilizations developed out of doors, as the homes of these early cultures were generally in tropic or semitropic climes. Their music has survived in the Near East and in the Orient

* Presented Feb. 19, 1947, Atlantic Coast Section, SMPE, in New York.

** Johns-Manville, New York, N. Y.

largely in pentatonic and whole-note scales. Harmony as we know it cannot be obtained using these scales. They are best suited to heavy octave melodies, or staccato tunes for flute and strings built over the various drum rhythms.

An example of this use of ancient scales is in Japanese music today. Their traditional music is played out of doors, in shrines open at the sides, or in houses constructed of thin wood, bamboo, and paper so flimsy and absorbent as to simulate outdoor conditions. However, as the Japanese have gradually adopted the fireproof construction of the west, their modern music has likewise begun to make use of our scales and to take on the style of western music.

In the Christian era the march of civilization was toward the temperate zone of Europe. During the early centuries the church became the seat of culture and the main source of developing musical tastes. In the main, the churches, temples, and cathedrals were of much greater volume than other structures and they were enclosed against the more rigorous climate. Stone replaced wood as more enduring materials were used.

These factors aided in prolonging reverberation of sounds because reverberation depends on the amount of space enclosed and on the hardness of the surfaces. The notes overlapped. The more primitive scales when used in such places provided dissonances which were unpleasant to the ear. The Gregorian chants arose. The diatonic scale came into popular use, particularly in early operas. The hurdy-gurdy grew into a harpsichord, then into the piano and organ. Bach, Beethoven, Brahms, Stravinsky, Debussy, Ravel; changing scales, new instruments, great composers—and new architecture.

There are many of us who remember the early silent motion pictures where the sound effects consisted mainly of a piano and the quality of the music was of little value except to cover up the sound of the projection machine and to fill the time of changing reels and repairing film breaks. The legitimate theaters, concert halls, and churches inherently either had good or bad acoustics and little was done about it.

"Acoustics" was about as vague a term as politics, as little known and frequently as aimless. During this period miles of wire were strung up in auditoriums all over the country and some of it still exists. While it was one of the early attempts at acoustical treatment it is known that it did no good at all.

In the early part of this century Professor Wallace Clement Sabine

of Harvard University put the acoustics of buildings on a scientific footing by establishing the relationship between reverberation time, room volume, and sound absorption.

The subsequent treatment of many rooms and the use of articulation tests have determined that the optimum value of reverberation for a room is a function of its volume. Also, it was learned that a room used almost entirely for music should be somewhat more lively than one of the same volume intended primarily for speech.

As long as we depended mainly on the power of our own voices and musical instruments, most of our auditoriums were fairly satisfactory. The bad ones were usable even though they were annoying. But when the audion valve, vacuum tube, and triode came into being the course of the entire history of sound changed. We could then amplify the sounds we knew, thus putting many times the sound energy into the same enclosed space. In this way the old acoustical defects were multiplied.

Sound came to us in the form of radio-receiving sets, public-address systems, and sound motion pictures. People accepted the deficiencies of these new forms of education and entertainment as long as the novelty remained. But soon they were complaining about the old halls that boomed and growled with reverberation and echoes. They wanted something better. And as the sound industry improved acoustics had to improve with it.

We had had experiences in our homes with the sound-deadening effects obtained by the use of heavy carpets, draperies, and similar materials; however, little was known of the very few commercial acoustical materials existing at that time. So the attempts to deaden the noisy rooms and halls were generally made with home furnishings.

Accordingly, upholstered seats, carpets, and acres of draperies made their sudden appearance. Draperies ranged through theatrical gauze to monk's cloth and heavy velour folds alone, or applied over all kinds of felts, jute, and cattle hair. Quilts, blankets, and rugs, too, were hung up in attempts to subdue the bouncing sounds.

The same unstudied treatment was given to early radio studios, recording studios, and sound stages. The pickup and recording equipment were just about as rough in those days as the rooms in which they were used, and the noisy scratch of early synchronized films would make poor entertainment today.

All of this made a growing industry conscious of the need to learn

more of the nature and behavior of sounds; speech and music in particular, for these are the intelligible noises which give instruction and pleasure.

It is obvious that the cure for reverberation is sound absorption; however, this cure can be excessive in two ways. Materials may be used which absorb only a part of the sound spectrum, or an excess of material may produce too much over-all absorption.

A room treated so as to produce selective absorption will give a very unnatural result. If the high frequencies are heavily absorbed

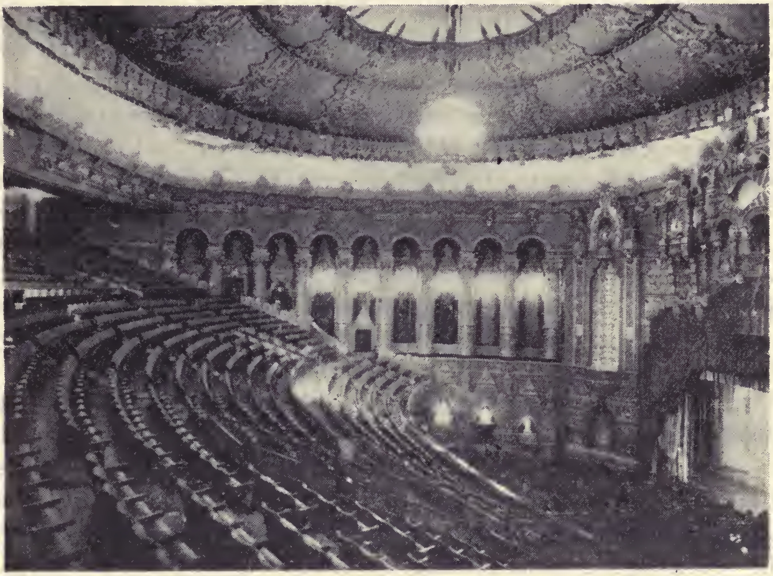

FIG. 1. Type of theater using treated domes, heavy ornamentation, and upholstered seats.

the room will be boomy and the voice and instruments hardly distinguishable because of the loss of overtones. The degree of absorption should be about the same at all audible frequencies to maintain naturalness.

Many studios have been treated with material intended mainly for high-frequency typewriter or knife-and-fork noise, and the musicians have complained that these spaces are too dead, or too boomy. These studios have been corrected by taking out some of the high-frequency absorbent until a balance was secured.

The second excess is too much over-all absorption, making the room approach zero-reverberation or "free-field" conditions. Here we go back to outdoor conditions for which our music is not suited. An acceptable balance must be secured based on study of old halls, long used and liked, or new ones thought to be better because of public acceptance of the results obtained in them. Knowing the upper and lower limits has been a great help in setting up proper reverberation times for various spaces.

When a room is to be used for recorded sound, both the originating studio and the hall should be treated slightly more than the rule calls for because of the additive effect of their reverberations. This is true of sound stages, motion picture theaters, and recording and broadcast studios.

Another fault commonly found in older theaters was echoes, or delayed repeats, of the original sound. These were generally caused by large domes, curves, and large flat surfaces. If a curved ceiling had focuses at the floor level or even multiples of this distance, disagreeable echoes were more than likely to spoil the seating down the center of the room. Most modern designers avoid these shapes and the domes of many of the old auditoriums have been heavily treated or new ceilings suspended under them with curves to kill the echo. An example of the use of a treated dome is shown in Fig. 1.

The modern theater is now generally constructed of splayed surfaces which tend to straighten the path of reflected sounds passing to the rear. The back wall is not curved to focus near the stage unless it is very heavily treated, and upholstered seats are used to act as compensation absorption with small audiences. This last item keeps the reverberation from varying too much between full and empty conditions and does not require such a wide swing in gain to operate the horns.

The recording studio is a special problem in acoustics. First the sound should be so well distributed as to require only one microphone, or a very few in any case. If possible the reverberation should be quite flat over the frequency range except for the high end where it should rise.

The scratch and circuit noises are still intense enough to make very wide range recording a little unpleasing. If the high frequencies, that is, the overtones, timbre, and brilliance, can be built up excessively by reverberation and attenuated electrically back to normal level, a high signal-to-noise ratio will be maintained and the scratch

considerably subdued. Such a treatment must be done carefully with as much attention to reflective surfaces as to the location and kind of absorbing surfaces.

Reflective materials are, generally, the floor which must be hard enough for its traffic, plastered surfaces, plywood, and transite. Plaster, plywood, and transite may be formed into polycylindrical and faceted or prismatic surfaces. These scatter sounds for better mixing. The deeper the offsets, the lower the frequencies which are affected. The sound-absorbing materials generally have a base of rock wool which will be covered by membranes of thin plywood, or perforated transite, to avoid too much high-frequency absorption.

FIG. 2. A Reeves Studio in New York City.

For the same reason, great care should be taken to use sparingly such materials as carpeting and draperies. (Note the serrated panels in the ceiling of Reeves' studio in New York which is shown in Fig. 2 and in the control room of this studio in Fig 3.)

The problem is virtually the same for the frequency-modulation studio, but it is not quite so rigorous for the more general amplitude-modulation studio because of the millions of limited-range receiving sets already owned by the public. Most of these run almost entirely on bass notes and almost twenty-four hours a day. However, as equipment is improved, all of these amplitude-modulation studios will have to be adjusted for high-fidelity sound.

There is another problem connected with all studios and places where we listen to sound. This is background noise. Practically all theaters are in urban areas with plenty of traffic noise all around.

and their problem has been solved by omitting windows, using heavy walls, and deep vestibules, heavily carpeted, and lobbies with double doors. We must expect to endure some objectionable background noise when we sit in the middle of a thousand or so people. Fortunately, we become psychologically deaf to their presence when the show is interesting. This is not true of a real studio. A recording or broadcast that carries with it traffic and fire-engine noise, or the sounds

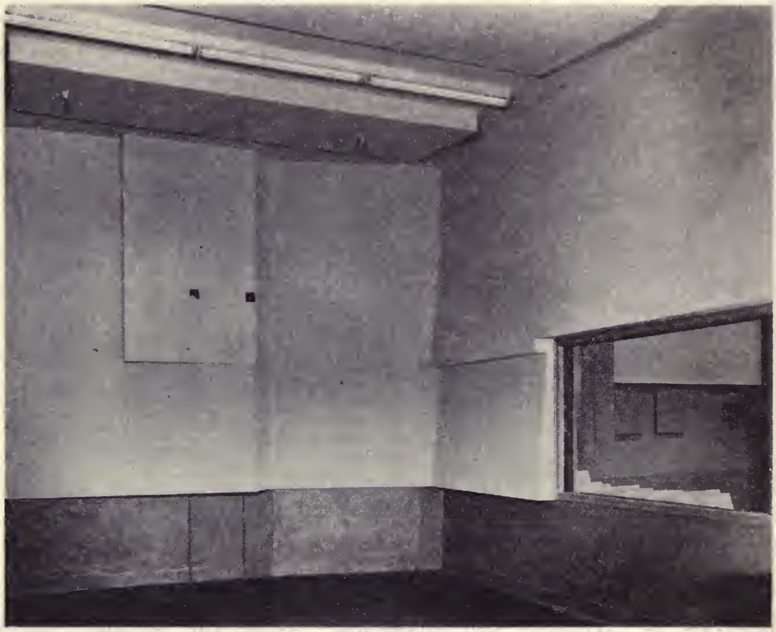

FIG. 3. Control room for studio shown in Fig. 2.

from other spaces in the building such as presses, elevators, and plumbing is not interesting. The background noise in a studio should be such that the intended silent moments are really silent and not distracting.

Such conditions can only be attained by sound isolation. This work bears no relation to the acoustics of the room itself and is a matter of construction and location. A single studio may be built far enough in the country to avoid all noise except thunder and airplanes, yet it still must be isolated from its control room and recording room to prevent feedback and pickup of machine noise. Most studios are

built in the cities to be accessible to talent, service, and other requisites. Here they must contend with other building noises and sometimes subways, heavy traffic, and near-by manufacturing.

There is no such thing as absolute soundproofness; at least not on earth. A body at absolute zero floating in an absolute vacuum might be said to be absolutely soundproofed. Under special conditions we are able to hear sounds at some pitches down to a point a little below zero decibels, which is a sound intensity of 10 to 16 watts per square centimeter. However, as a person's body makes a noise of about 14 decibels just doing its regular work of pumping, digesting, and breathing we do not often experience quiet below that.

Ordinarily a studio is considered good if the background level can be held to the twenties of decibels. Naturally, more soundproofing will be needed in a noisy than in a quiet location. Suppose we build a wall which will attenuate sound 40 decibels. If the level around it is 70 decibels, the level inside the walls will be 30 decibels; if the level outside rises to 90 decibels when a truck goes by, the inside level goes up to 50 decibels. In such a location more soundproofing will be required.

The foregoing indicates clearly that a proposed studio location should be examined before construction is contemplated in order to determine the problems to be expected from extraneous sounds. This survey should include observations of the background noise level, the amount of vibration in the structure, its mass and rigidity, and its allowable floor loading.

A building on Third Avenue in New York was recently examined in order to determine if it could be used for recording studios. Because of the scarcity of space a thorough examination was made of it. It was an old building with lightweight wood joist floors and ceilings which could not stand the weight of studio construction. The ceilings were so low that if we had used the necessary space for isolation and treatment, there would hardly have been room left for a bass viol. And besides, every time a Third Avenue elevated train passed by the whole building shook and the noise level rose to a point which made conversation impossible. We had to advise against signing the lease.

The weight of the structure is very important as the heavier the walls and slab construction, the better it resists vibration and passage of sound. A 12-inch brick wall is much more soundproof than a stud partition, as everyone knows.

The majority of the better studios are constructed of the "room-within-a-room" principle. The interior surfaces of the studio are "floated" away from the actual building floor, ceiling slabs, and structural partitions. This "floating" is accomplished by means of felt or spring isolators which carry or support the inner surfaces of plaster and floor slab. An example is shown in Fig. 4. Here the walls and ceiling have already been isolated, sound-absorbing panels installed, and the floated floor is being constructed.

FIG. 4. Studio in process of being isolated.

Entrances to the studio are accomplished through soundproof doors. The ventilating system is flexibly connected to the room and the ducts are lined with sound-absorbing material. The electrical conduits must be flexible, too, where they enter. Heavy double glass is used for observation windows. Each glass is of different thickness or tilted out of parallel with the other to reduce transmission.

After all of this is done the isolated studio is ready for acoustical correction of the interior which means the control and distribution of reflected sounds within it. This is accomplished, in the manner already discussed, by sound-absorbing material for different pitches of sound and reflecting material at suitable angles for distribution of

sound. An example of a completed studio is shown in Fig. 5. This is Studio 8-H of the National Broadcasting Company in New York.

The associated control room is soundproofed from the studio to prevent feedback. It need not be quite so soundproof against outside noise as the studio itself, but it must have nearly perfect listening conditions for proper monitoring of a program, judging quality, microphone placement, and poor performance.

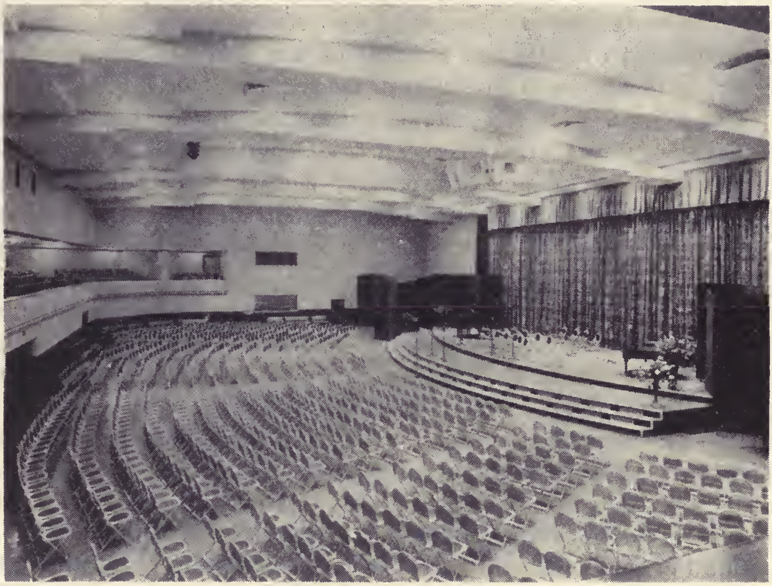

FIG. 5. Studio 8-H of the National Broadcasting Company in Radio City, New York.

The higher the fidelity of the program, the more necessary it becomes to try for acoustical perfection in both the studio and the control room. A place used primarily for playing records is relatively unimportant compared to a studio originating frequency-modulation programs.

All of us are interested in television. A studio used for telecasting is in some ways quite different from those used for broadcasting and recording; yet they are similar in many respects to the present sound stages for motion pictures. Here, again, the first requirement is isolation from extraneous noise to prevent transmission of something foreign to the program.

In television as in sound motion pictures, two senses are being catered to, the sound and the vision must match. If an outdoor scene is being shot the sound should not be reverberent as though coming from a rain barrel; and conversely an indoor scene must carry a certain amount of room acoustics to make it sound real. The first condition is secured by covering practically all of the interior surfaces with a very efficient sound-absorbing material, to allow as little echo and reverberation as possible. In the second condition, when shots require reverberation, the reflection of sound is usually accomplished by reflective surfaces of sets and flies, or by adding reverberation through chambers or mechanical devices.

The reverberation chamber is a room with very hard surfaces. The echo chamber is one where a desired length of sound path may be used between microphone and speaker. One mechanical device is composed of a series of long damped springs with the alternate ends mass-loaded and clamped for reflection of mechanical vibration induced by the signal. These devices may be used as a parallel signal path so as much of their effect may be added to the signal as is desired.

A television studio should have a ceiling height capable of accommodating lighting. Usually catwalks are used to place and mount special lights. The ventilating system must be adequate to handle the increased load caused by the heat from the intense lighting. The whole effort is to bring as many scenic conditions as possible under a protective roof and within soundproof walls and close to the elaborate equipment needed for pickup and telecasting a program.

In all of these enclosed spaces we are attempting to produce programs and entertainment which will be the most natural and pleasing to the greatest number of people. For this reason sound coming with television and with motion pictures, too, should match the scene conditions. If the actors are evidently in a living room their voices should sound as though they were in a normal-sized room and not as if they were in the bathroom, or out in the woods. Music, too, should have its normal reverberation and not give the impression that the violins are stuffed with cotton.

This whole science of architectural, or space acoustics, as we have called it, is a rather simple thing. It is just a matter of common sense to have our studios treated to give them natural sound and to have our theaters designed so that everyone in them hears the sound as it should be. If the rules previously stated are followed there should be no reason why this goal cannot be attained.

DISCUSSION

MR. RIDGEWAY: What can you tell about the latest methods of motion picture studio sound treatment?

MR. JAMES Y. DUNBAR: We do not get as much exposure to that problem on this coast as they do in the west, but the film sound stage involves the same process of treatment as the television stage. One of the important things is to keep extraneous noise out of it. It should be fixed so that extraneous noise is not added to the recorded sound. Of course, a great deal of sound is dubbed in at places suitable for sound recording after the picture is shot; but where it is not, the acoustical treatment has to be such that one can obtain a wide variety of scenes and sounds under one roof, from outdoor effects down to room effects.

The treatment should be the most efficient absorbent obtainable to prevent unnatural effects. If you have a place that has only high-frequency absorption and is rather boomy, you know from the sound that you are not outdoors, even though the scene tells you that you should be.

MR. RIDGEWAY: Have there been any recent developments in materials used in motion pictures, other than rock wool?

MR. DUNBAR: The use of rock wool continues, although its fabrication has changed a bit. One way of absorbing the lower frequencies is to make the treatment thicker and to space it out from the hard walls or ceiling. This has been taken to quite a length in what they call anechoic or nonechoing chambers. I think the early work on these was done by Meyers in Germany. This process consists of cones or pyramids of rock wool three or four feet in length. The entire room surface is covered. It is an excellent treatment, but the cost is more than could be allowed in the construction of sound stages. It is only in special testing chambers that such a treatment is used. It was used in one of the test rooms in the Brooklyn Navy Yard.

MR. BARNES: Is there any preferred ratio of length or breadth to height, in studio construction?

MR. DUNBAR: There has been a great deal published on that, and I say, "No", within certain limits. I have known some people with excellent space for a studio who wanted to restrict it to a ratio of 2:3:5 or 2:3:6, or 2:3:4. There is no particular reason for this.

Through the long period in which we have acquired our sense of music appreciation and sound, we have become accustomed to living indoors and most of our experience has been indoor experience in rooms of varying sizes. We have gotten away from the Greek amphitheater and expect to notice some *room effect.*

In a room of a size which is peculiar, like a very large one with an excessively low ceiling, the poor room proportions would be apparent to a blind man. A blind man can get some sense of the dimensions of a room by walking into it and hearing reflected sounds. We may not be so conscious of this as a blind man, but we know a room has to be proportioned somewhat near the sizes we are used to in our living. If studio size is within this range it is sensed as all right; if not, custom and binaural hearing will probably tell us that it is peculiar.

MR. BARNES: Would a room that had a ceiling height more than the width be troublesome?

MR. DUNBAR: It is likely to be unless treated as a room turned on its side, which it could be. And it would probably still be troublesome!

MR. C. R. KEITH: Nowadays, 16-millimeter motion pictures are shown in classrooms and other rooms not particularly designed for reproduction of sound. I wonder if you have any particular suggestions that might apply to such locations.

MR. DUNBAR: More and more, I have had architects ask for mineral treatment of classrooms, and I think a great many of the modern schools will have treatment in the classrooms to adapt them to the use of visual aids and use of motion picture 16-millimeter films. Most of the newer schools are having acoustically treated classrooms specified.

MR. KEITH: Is there any treatment of existing rooms which might be practical, or is it usually necessary to revamp completely the whole room?

MR. DUNBAR: No, that is not necessary. Many materials can be glued, clipped, or nailed on. And it is possible to secure just as good a treatment in an old room as a new one.

MR. LEWIN: In cases of small studios, used for a commentator talking into a microphone, is the best treatment to make the rest of the room as dead as possible?

MR. DUNBAR: No, a muffled effect will result. It is better in a small room to use considerable low-frequency absorption. A male commentator has a low voice, and the common treatments have no effect on the fundamental. If you do not absorb an excessive amount of the highs, a richness, distinctness, and clarity to speech stand out.

MR. LEWIN: Would it not appear that when a person is talking very close to the microphone practically all of the sound is being picked up directly?

MR. DUNBAR: Practically all of it is.

MR. LEWIN: What is picked up from the wall should be less important, and might as well be deadened.

MR. DUNBAR: But if you have a *perfectly* dead room condition, talking into a microphone is not too pleasing to the speaker.

MR. SAWYER: Would you care to comment at all on tests that you might apply to an important room such as broadcast studio or recording studio? In other words, do you depend pretty largely on your calculations in advance, or when a job is done, do you make some measurements and modifications?

MR. DUNBAR: We have made quite a few reverberation measurements before and after treatment, and after measurements are generally fairly close to the calculated. The treatment that is used has been laboratory-tested for the coefficient, so we know how much absorption we are putting in. There may be other things like the calculations of, say, a plaster wall which looks rigid. It may be very thin and quite flexible and therefore very absorptive, and we may have misestimated it in our calculations. An actual test will show that up.

I might ask Mr. Gurin how close he came on his last measurements. Would you mind telling us?

MR. GURIN: Ten per cent.

MR. DUNBAR: That is close. I wish we could always do as well.

MR. SCHLANGER: Much has been said on the subject of no absorption treatment at all. In small theaters, to what extent is that possible today?

MR. DUNBAR: I might point out that when La Salle Playel was designed in Paris, all sound was focused back to the audience; but one item that was overlooked was reverberation. Treatment had to be installed afterwards to reduce

the excessive reverberations. This treatment consisted largely of absorption applied on the back wall.

MR. SCHLANGER: How about a theater of from 300 to 600 or 700 seats?

MR. DUNBAR: I think if you hold down the unit volume and maintain some nonparallelity of the surfaces to straighten the reflecting paths a bit you would still have to have some back-wall treatment. If the volume is excessive in proportion to the number you are seating, a large amount of absorption must be used to hold the reverberation down.

MR. SCHLANGER: How about not letting the paths come back to the source?

MR. DUNBAR: This can be helped by sloping the back wall. If the back wall focuses toward the audience, the reflected sound meets with the oncoming sound. You might have sufficient lag to cause a disturbance, or echo in such an area.

MR. SCHLANGER: Assume you could reflect the sound downward.

MR. DUNBAR: If you have heavy absorption on the floor that would help.

MR. SCHLANGER: The audience would help, too.

MR. DUNBAR: Yes, it would. Another way would be to slope the back wall up and put heavy sound absorption on it; the second reflection is then negligible. Also you might scatter it by broken surfaces and absorption for good results.

MR. LEWIN: In a sense, I think you have given us two concepts here. They are somewhat contradictory, because you outlined the way you treated a theater and the desire for having absorption on the back wall, on the ground that the sound presumably is headed in one direction and should not go back the other way, but when reference was made to recording studios, you gave us the inference that the idea of a live-end and dead-end was wrong, which one might assume to mean that you would want to use that studio one day with the orchestra on one end and another day with it on the other.

Now, if the absorption on the back wall of a theater is good, why isn't a live-end–dead-end studio desirable on the ground that it is a large studio where you have audiences in one end and an orchestra in the other?

MR. DUNBAR: To keep a theater from being a live-end–dead-end, you put treatment on the back wall. The front wall is already dead, for you have considerable absorption on the screen side. To go back to the legitimate theater with flies and props and curtains, the proscenium area is very dead. But if your highly directional horns with considerable intensity are pointing toward an untreated hard wall, you can expect trouble. You may expect a lot of trouble in a studio if you start shooting such a horn around and try picking it up on a microphone. In a motion picture theater you do not want to be conscious of the acoustics of the theater itself but to hear the sound as though it were coming from the picture shown. The acoustics of a studio, however, are a part of the sound picked up for recording or broadcasting.

MR. JORDAN: A question occurs to me as to the effect of acoustics. I mean, a great deal of trouble is taken in designing proper acoustics for reproducing a play in a theater, and proper acoustics for the recording setup. Now, if you have proper acoustics in the recording setup, and then you reproduce it in another space with proper acoustics, do not the acoustics of the first add to the second, and thereby increase the reverberation?

MR. DUNBAR: Yes. The reverberations of the place in which you picked up

the sound add to that of the new place in which it is put. The addition is not arithmetical but the confusion is.

MR. JORDAN: On that basis, if the acoustics are designed for the reproducing end, why would not the proper acoustics in the recording end be with no reverberations whatever?

MR. DUNBAR: There are several reasons. One is, you do not know what room conditions you are going to have when you listen to it. The recorded programs might be given in any kind of room. A recording with no room effect is a dead staccato thing. Another reason is that musicians cannot work well in a dead room.

MR. JORDAN: That is true, but it has been my observation that quite often a recording which has been made under what are thought to be ideal studio conditions, and played in a very modern theater which was supposed to have been designed by acoustical experts, sounds pretty terrible.

MR. DUNBAR: A lot of theaters do reverberate for small audiences. There are many times when the amount of reverberation in a theater is a reflection of how much money has been spent to correct it. Exuberance might have led toward too much and of the wrong kind of materials, and then some other faults may show up.

MR. DAVIS: Are there limits of temperatures and humidity within which acoustic measurements should be made?

Would not there be a difference if the room were cold than if it were at normal temperature?

MR. DUNBAR: It changes the high-frequency absorption to some extent. At 3000 or 4000 cycles it would have a decided effect, but below that, I do not think it makes much difference whether it is hot or cold, or moist or dry. The low frequencies seem to be little affected by it, unless the sound-absorbing material is saturated with water.

MR. SELIG: Do pillars in a room have any effect on acoustics, and is there any way to treat them?

MR. DUNBAR: Yes, they do. It depends on how large they are. The larger they are the lower the frequency that is scattered from the pillar surfaces. If the space in back of a row of large columns is highly reflective, you will have reverberant feedback. If the columns are large, you get a scattering effect. In the Beaux Arts Building we used elliptical forms for coverings for the columns, and it seemed to work out very well; at least, the recordings sound pretty good.

CHAIRMAN JAMES FRANK, JR.: Are there any new types of treatment particularly recommended for theaters in contrast to the types used during the first five or ten years after sound was introduced to theaters? Where is the best average place to put them?

MR. DUNBAR: I think I have already touched on that. The most important place is the back wall. If you have many balconies, you have the absorption of the balcony areas, and you have less back wall to treat.

The type of treatment has not changed a great deal. I think rock wool is now the basic material. Theaters nowadays have to use fireproof materials. Rock wool offers good absorption and is fairly inexpensive. The usual coverings for it are flameproof fabrics or glass cloth or perforated transite or metal. I am in favor of a material that reflects high frequencies, like perforated transite, or even thin light flameproof plywoods.

MR. RADAMACHER: Where is there such a theater that has that type of treatment?

MR. DUNBAR: Eastman Kodak has a small projection studio theater that is treated that way, and it has been pronounced very satisfactory. Studio 8-H of the National Broadcasting Company and Radio City Music Hall are also good examples.

MR. RADAMACHER: How about acoustic plaster?

MR. DUNBAR: That is a little indeterminate. Its value depends on the workman who puts it on. If he presses it on too hard, it becomes dense and will absorb little sound. If it is applied properly it may fall off in places on account of poor bonding. It is not a fabricated material of fixed absorption, so its absorption may vary considerably. Materials of that type, when painted, lose a great deal of absorption.

MR. GRIFFITH: I am very much interested in the historic shift of musicians from outside to inside. Are there any treatises on that which might be available?

MR. DUNBAR: It is a theory of mine. I don't know whether there is anything published on it although there is a reference to it in the article on acoustics in the *Encyclopedia Britannica*.

MR. LEWIN: Would you care to say what is the ideal reverberation value you can get? Do you try to get it flat?

MR. DUNBAR: No, you usually try to get it fairly flat, but with the reverberation tilted up a little at the low end and at the high end. The use and volume of room both determine the amount of reverberation and the shape of the curve.

MR. FAY: Have there been any tests in recent years, by an unbiased source, of the absorptive values of different types of chairs manufactured by various theater-chair manufacturers?

MR. DUNBAR: The National Bureau of Standards made some tests a number of years ago. There is also a new Acoustical Material Association booklet on absorption values which includes some information on chairs.

MR. MCGUIRE: Mr. Braun has been connected with the Radio City Music Hall since it opened. I wonder if he would like to make any comment on the subject we are discussing.

MR. H. B. BRAUN: You asked before whether we have any trouble. I might touch on just one point. That is the use of acoustic plaster. In addition to the uncertainties because of the manner in which the material is applied, there are also difficulties as a result of time. Although we have no absolute figures, we are quite certain that acoustic plaster does age and lose its effectiveness, and as a result, we have some echoes now which did not exist immediately after the construction of the theater. Our rear walls are very heavily treated, and some correction was applied subsequent to the completion of the building by means of changing the contours of some of our surfaces.

MR. LEWIN: They have something over there like a public-address system. So far as I know it is an unusual installation. Has it any effect on this problem?

MR. BRAUN: It has this effect: because of the large size of the auditorium, which is nearly 2,000,000 cubic feet, it is necessary to reproduce at levels considerably in excess of unity. We are creating artificial reverberations by means of a reinforcing system.

MR. LEWIN: Has the acoustic plaster ever been painted since it was installed?

MR. BRAUN: No.

MR. BOYCE NEMEC: Would you describe the system of suspended absorptive cones that have been proposed for acoustic systems in rooms that can't be treated by normal wall or ceiling treatments, and give us some typical applications where a treatment of that kind would be suitable?

MR. DUNBAR: They are functional sound absorbers developed by the Radio Corporation of America. The system is used primarily in places where the ceiling is so high or has so many pipes and obstructions that it is difficult to do anything else. They are cones, and two together make up a unit. They are hung up or strung up on stretched wires across the room. For a long time we have known that by breaking-up treatment from a concentrated area, it is more efficient per square foot. For instance, a single panel of 12 × 12 feet on the ceiling will have a great deal more effective absorption if it is split up and each of the 144 square feet installed separately about the room. At the present time, the cones cannot be used in New York because they are nonfireproof. We are figuring on some means to make them fireproof.

MR. NEMEC: Would you give us one or two examples of the type of rooms that can be treated with them?

MR. DUNBAR: One is a workshop where you have piping and belting, over the ceiling, and where you cannot put on so many square feet without excessive waste in cutting. Another is the case of an excessively high ceiling where, if you treated the ceiling, it would do very little good, but if you hang the material halfway down, you could increase the absorption.

MR. BRAUN: Can you effectively reduce the volume by that method?

MR. DUNBAR: Yes, and you get the absorption coming and going, if you hang enough of them. Generally they are hung pretty thick in a case of that kind.

MR. GRAF: What is the material used for those cones?

MR. DUNBAR: Very light wood fibers put together in a mat form, something like papier-mâché. They are matted in shapes similar to a Mexican hat, and a pair of them together form a unit. When the sound energy flows toward it, instead of taking out just what strikes it, the sound waves passing by tend to buckle in behind and be absorbed the same way, so you pick up more sound energy than you do with the projected area of the same material applied flat on the walls.

CHAIRMAN FRANK: Would you say that they could only be used in a place where decoration was not such an important factor?

MR. DUNBAR: That would be my idea, although they could be used as part of a design.

MR. GRAF: Are they usable over a rather wide frequency range so they can be used effectively in areas where other treatments would not be effective?

MR. DUNBAR: They have a rather wide frequency range of absorption, but so have some other materials. It is not new from that standpoint but it is an economical form of obtaining absorption with a low-cost installation, where a nonfireproof material would be acceptable and where other materials would be difficult to install.

MOTION PICTURE RESEARCH COUNCIL

The newly incorporated Motion Picture Research Council, Inc., succeeds the former Research Council of the Academy of Motion Picture Arts and Sciences. Wallace V. Wolfe, active in Society affairs for many years and current Chairman of the SMPE Pacific Coast Section, has been appointed Director of Research by the Board of the Association of Motion Picture Producers which will administrate and finance the Council's operations.

Y. Frank Freeman, Chairman of the Board of the Association and also Chairman of the Research Council, announced this change and also reported that the Association recently appropriated $150,000 as an initial allotment to promote an industry-wide research program.

The Council will expand its activities in all phases of motion picture development work, including:

1. Designing and supervising construction of special equipment and processes for motion picture production.

2. Applying new research developments to the industry and co-operating with universities and industrial research groups.

3. Standardizing equipment and processes within the industry to permit better equipment to be manufactured more efficiently.

The Motion Picture Research Council will be able to provide manufacturers with specifications on equipment which represent the desires of all the studios, and will welcome and act as a clearing house on all new ideas and information pertaining to motion picture production.

William F. Kelley, Manager of the Academy Research Council for 11 years, will continue in his position as Manager and will take on additional responsibilities as assistant to Mr. Wolfe. The Council has engaged additional motion picture engineers and from time to time will assign others to specific projects.

Present members of the Research Council, representing technical departments of each of the major studios, will assist the new staff. In addition to Freeman these members include Thomas T. Moulton, vice-chairman, 20th Century-Fox; John Aalberg, RKO-Radio; Daniel J. Bloomberg, Republic; Farciot Edouart, Paramount; Bernard Herzbrun, Universal-International; Nathan Levinson, Warner Bros.; Lohn Livadary, Columbia; Elmer Raguse, Hal Roach; Gordon Sawyer, Samuel Goldwyn; and Douglas Shearer, Metro-Goldwyn-Mayer.

Design of new equipment will cover items not now available on the market, but the Council in supervising construction of working models by existing supply companies will not become a manufacturing organization.

"The Council will analyze studio problems and work out solutions by combining the best ideas of the studios' own technical experts," Freeman said. "It will then serve as a co-ordinating agency to work with manufacturers to provide standardized equipment at economical prices.

"We are fortunate in having Mr. Wolfe, with his outstanding record, to head our new program. The need for more thorough research into all aspects of film production has long been evident in Hollywood and other centers. We are confident that our new program will strengthen Hollywood's leadership in the field of motion pictures.".

Independent producers not now members of the AMPP will be extended the privilege of participating in the research work and its benefits, Freeman added.

SOCIETY ANNOUNCEMENTS

SMPE MOVES

Because of the rapid growth of the Society of Motion Picture Engineers and the resultant increase in the office staff, it was found necessary to move Headquarters from the Hotel Pennsylvania in September. The new address is ninth floor, 342 Madison Avenue, New York 17.

It is hoped that our members will call upon us whenever they find it convenient. We extend to them a hearty welcome and hope that many of them will avail themselves of the opportunity to make us a visit.

Boyce Nemec
Executive Secretary

NEWS AND NOTES

It is planned, in the very near future, to publish material concerning our members, as well as information on new products which will appear in the market. Therefore, it is desired that members of the SMPE who make changes in position send to the Editor of the Journal announcements concerning themselves. These write-ups should be phrased in a formal style, should be accompanied by a glossy print of the writer, and should not be unduly commercial. Photographs should be of the formal, studio type, preferably 8 by 10 inches in size.

The subject matter should contain the following: date and place of birth; academic degrees granted; dates and places of employment; memberships in other scientific organizations. Necessarily, this invitation can be extended only to members of the Society, and the SMPE reserves the right to edit this material as it sees fit.

New Products notes should be about items of outstanding interest to the motion picture engineer. The commercial aspect should not be stressed, but the scientific value should be emphasized. Wherever possible, glossy prints of the article in question should be submitted with the write-up. The SMPE reserves the right to accept or reject material and to rewrite it if necessary.

EMPLOYMENT SERVICE

POSITION WANTED

SOUND RECORDING ENGINEER: 16- or 35-mm equipment, single or double system. Preferably educational or industrial films. Free to travel. For details write or phone Marvin B. Altman, 1185 Morris Avenue, New York 56, New York. Telephone Jerome 6-1883.

JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

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Indexes to the semiannual volumes of the JOURNAL are published in the June and December issues. The contents are also indexed in the *Industrial Arts Index* available in public libraries.

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JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

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A TEST REEL FOR TELEVISION BROADCAST STATIONS*

M. R. BOYER**

Summary.—*After rechecking the work of the Subcommittee on Film of the Television Committee, it was found that broadcast stations needed a test reel which would allow dynamic checks of their systems. A reel was manufactured and its possible uses are described.*

In the years since the publication of the report by the Subcommittee on Film Tests of the SMPE Television Committee[1] much progress has been made in television broadcasting. It was felt that some of the work of this committee would bear repetition on the improved systems in order to check previous results.

A suitable reel was secured and four prints were made using normal- and low-contrast stock, and printing at various light points. These were then projected, transmitted, and viewed on the monitors of four different stations. In general our results were as follows: A print two points lighter than normal televised better than a normal print; and the less brightness range in the original subject the better the details were reproduced in the high lights and the shadows. Where no automatic bias control was used, a flat print projected better than a print of normal contrast. This agrees quite well with the previous report, although in this case all tests were made using an iconoscope as a pickup tube.

Again the above conclusions conform with theory in that the lighter print allows more light to fall on the mosaic plate and so requires less amplification. Also, low-brightness range in the original scene or

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* Presented Oct. 16, 1945, at the SMPE Convention in New York.

** E. I. du Pont de Nemours and Company, Photo Products Department, Parlin, N. J.

print means that the picture-tube screen, capable of limited-brightness range, can more accurately reproduce the original without losing details in either the high lights or shadows.

In the course of these tests two things were noted. The system performance was usually checked prior to broadcasting by projecting with a slide projector, a still pattern onto the mosaic. No dynamic test of the system was made prior to going on the air. Second, no method was currently used to check the over-all tone reproduction of the system when projecting film. All checks had been made with static test patterns.

In discussing these two observations with station engineers it was learned that a film containing one or more somewhat standard test patterns would be welcome. At the same time it was decided that a step-density wedge which could be photographed from the monitor tube would allow a dynamic check of the whole system, should a station desire to make such a check. These two features, plus various types of scenes printed at different light points, apparently would comprise a most welcome aid to station engineers.

Accordingly work was started in assembling such a reel. It was found that each station had its own preferred test pattern, in addition to those that had been worked out by the Radio Corporation of America for checking their iconoscopes and kinescopes and which had been published in the literature. Also, after running the partly assembled reel at several stations, other suggestions were made for types of patterns to be included. One of these was the superimposition of dots with varying densities on each step of the wedge. In making the titles, it was felt that it would be helpful if one title had black letters on a white background, and the following title had white letters on a black background. This would indicate the time required for shading successive scenes where each scene was drastically different.

After frequent checking with four major stations, the new reel was assembled. It must be realized that many test patterns had to be omitted, and those used by three stations were included as being typical.

The reel is composed of the following scenes and titles. A description of the chart and what may be noted in transmission defects is described.

Titles 1 and 2 are for use in checking the rapidity with which shading can be accomplished when going from a clear background to an opaque background.

The NBC chart is so designed that the ratio of the radius of the large circle to the inner circle is 4 to 3 or the prescribed aspect ratio. If the circles have a true form the aspect ratio is correct. However, if the circles have an elliptical shape the pattern is too wide when the main axis is horizontal, and too narrow when the axis of the ellipse is vertical. Nonlinearity in ratio of scanning is indicated by an egg-shaped outline.

The "eye" of the pattern is divided into four rings of equal density differences. Therefore for true reproduction of high lights and shadows the apparent difference in brightness between adjacent rings should be the same.

	Subject	Footage	Approximate Running Time
1.	Title—Clear Letters on Black Background	30 ft	20 sec
2.	Title—Black Letters on Clear Background	30 ft	20 sec
3.	NBC Wedge Chart	90 ft	1 min
4.	DuMont Wedge Chart	100 ft	1 min
5.	Philco Wedge Chart	100 ft	1 min
6.	Checkerboard Chart—RCA	100 ft	1 min
7.	Step Densities	100 ft	1 min
8.	Step Densities with ΔD	100 ft	1 min
9.	5 Scenes—Normal	90 ft	1 min
10.	5 Scenes—2 Light Points under Normal	90 ft	1 min
11.	Last Scene—4 Light Points under Normal	6 ft	4 sec
12.	Last Scene—6 Light Points under Normal	6 ft	4 sec
13.	Half and Half	60 ft	40 sec

The RCA chart is designed so that the squares are duplicated in sections allowing the defects to be localized. The shape of the main square and subordinate squares indicate the geometrical properties of the image. Because the chart is designed with a height of three squares and a width of four squares, the aspect ratio is easily checked. Any nonlinearity in either direction will be shown by a change in shape of the squares.

	1	2	3	4	5	6
Density:	0.23	0.48	0.92	1.50	1.77	1.80
Transmission per cent:	0.59	0.33	0.12	3.2	1.7	1.6

Any pairing in interlaced patterns will be shown by an uneven appearance in the horizontal wedges at the point of highest resolution.

Density-step tablets are inserted so that an over-all check of the contrast-transmission characteristics of the system can be made by direct photography of the tube screen.

Step densities with ΔD is a repetition of the step-density tablet but has dots of density 0.1, 0.2, and 0.3 superimposed on each of the six densities. This chart shows the minimum density differences which can be picked up at various locations along the tonal scale.

Five scenes, printed "normal" are a series of typical scenes from du Pont's "Soldiers of the Soil" printed at normal print density for theater use.

Five scenes, printed two points light represent an average density 0.04 less than normal and transmit 10 per cent more light.

Last scene printed four points light is printed four points lighter than the normal print. It has an average density of 0.08 less than normal and transmits 20 per cent more light.

Last scene printed six points light is again printed light but this time six points lighter than normal. It has an average density 0.12 less than normal and transmits 32 per cent more light.

The gradations in the sky areas of this scene form a practical application of the second density tablet.

Half field clear and half opaque and reverse is to check ability to keep sharp demarcation, or pairing. It also indicates the memory of the iconoscope mosaic.

ACKNOWLEDGMENT

We should like to acknowledge the kind co-operation of National Broadcasting Company, Columbia Broadcasting System, DuMont Laboratories, Inc., Philco Radio and Television Corporation, and General Electric Company in furnishing either material or suggestions, or both, in the preparation of this television test film.

REFERENCE

[1] Report of the Sub Committee on Film Tests—SMPE, 35, 6 (Dec. 1940), pp. 580–583.

THE SHOWMANSHIP SIDE OF TELEVISION*

RALPH B. AUSTRIAN**

Summary.—*The possibilities of theater television are discussed strictly from the box-office viewpoint. There is also a compilation of the many events which would make good box-office fare, and a description of many new uses to which theater television may be put which would attract people to the theater. How theater television may supplant the present motion picture programs and a positive viewpoint on theater television as a legitimate and necessary adjunct to the motion picture theater are also considered.*

During the twenty-six years I have been associated with the radio, motion picture, and television industries I have developed great admiration and profound respect for the engineer. I can recall no instance so far where in any of these arts the research or the practical engineer has failed to deliver first a technically workable, and then a commercially feasible instrumentality. Of course, you always hear the calamity howlers dismissing a new invention by wailing: "It can't be done"—"It's no good"—"It's a novelty"—"It won't last"—and so on. But there's a homely proverb which warns: "During the time you spend listening to the reasons why a thing can't be done, some one else is doing it."

I feel I can safely make the following assumption. The engineering fraternity is going to produce a technically feasible theater television system for the motion picture and television industry. The question is, what are we commercial men, the producers, the showmen, the merchandisers, the exhibitors, going to *do* with this technically perfect system? I, for one, am very much in favor of theater television. I have not heard many opinions one way or another from nontechnical people in the field of motion pictures. But I *did* run across a paper on theater television written by an engineer—a practical engineer, too—which set out to prove that, in the final analysis, television had no place in the theater because it could not deliver to a theater audience a program which was high enough in showmanship to make the show pay. This paper surprised me tremendously, largely because for the first time in my memory, here was a defection in the ranks of the engineers. Here was one of our own number vehemently stating that

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* Presented Oct. 24, 1946, at the SMPE Convention in Hollywood.

** President, RKO Television Corporation, New York, N. Y.

theater television would probably never be commercially possible. This is a very tender subject for an engineer to comment upon. As a matter of fact, in the past, questions of this nature have proved themselves to be very tender subjects for some of the greatest names in the motion picture industry.

Let us go back some twenty-one years ago when the engineers who had developed a device for making talking motion pictures tried to convince the producers of silent motion pictures that they had a salable commodity. The record contains some very interesting facts. Let me read you some of the utterances of men who were and still are big names in the motion picture industry. All but one of them whom I shall quote are alive and active in business today, so for that reason, I shall not mention any names.

The head of a company said:

"I do not know what 1929 will bring to the industry and neither does anybody else. Last year brought talking pictures. No one could have predicted what a rage they would become. In my opinion they will be just as much a rage next year. But I think that as we get further into them, we shall find that eventually talking pictures will be restricted to certain types of productions rather than that the trend will be to make all pictures talk. *The silent picture technique is too well established and its popularity too widespread to permit a variation of its form, no matter how interesting it is to the public, to dominate the thing itself.*"

A great theater chain head, said:

"Whether the major feature picture success of 1929 will be all-talking or part-talking or synchronized or silent, I believe it is impossible for anyone to say at this moment. Certainly the combination of the advantage of the silent picture in its swift action, its pantomimic advantages, and its photographic beauty, combined with the proper musical setting and *augmented in its climaxes with spoken dialog would seem* at the present minute to be the outstanding picture success of the coming year, always provided, however, that the story is worth the telling. With the prosperity that is in the country today I look for continued prosperity in the picture theater, if production measures up to the standards which will be demanded of it."

(This was a masterpiece of carefully calculated indecision.)

A sales manager said:

"The introduction of sound and talking pictures has created a new clientele at the box office and will draw to the motion picture theater this coming year millions of people who heretofore have never patronized theaters to any great

extent. This will reflect in a healthy condition to both the producer and distributor. It is my opinion that no theater in a city of any size can exist without presenting some part of its program in sound or dialog. However, I do not wish you to construe this statement to the effect that silent pictures should be eliminated. I contend that a fine silent picture properly synchronized to music will draw as well as any talking picture."

The head of a great studio said:

"A passing fad," said Mr. X, of the talkies. He added that "they might be all very well for the moment, but that the traditional silence of the silent drama would never die. When the public had had time to become fed up with this mechanical novelty, it would rally back to the old standards of subtitles and speechlessness."

A very well-known writer both for radio, pictures, and television wrote a magazine article in November, 1929, entitled "The Movies Commit Suicide". I quote herewith a few of his more precious observations:

"After some twenty years of being only in its infancy, the moving picture which gave promise of an interesting adult life, has again suddenly become senile and garrulous" .... "The effect of the new movies on the stage will depend largely on its effect on the old movie. According to the enthusiasts, the silent movie is doomed. I should say that in that case, the stage, although it has nothing whatever in common with the silent movie, will also go under. If the talking movie can undermine one, it can undermine the other" .... "The alternative which I think very likely to happen is that the film with just dialog will become a separate form of entertainment drawing to itself nearly everything tawdry and vulgar in the silent film and leaving the silent film in the hands of people, mostly foreign and amateurs able to appreciate its values" .... "It is a little too early to declare that the talking movie picture will become a cesspool for both the movie and the stage. I think that this is likely to happen because the movies are still in the hands of producers and directors who seem never to have taken the slightest interest in their own medium and have never studied its resources, its mechanism and its technique and its effect."

What an indictment this was. The jury, however, brought in the verdict of "not guilty".

A great director-producer said:

"Speech will be used by those directors who do not understand the capacities of the moving picture, whereas those who do, will extend their mastery over their own instrument instead of calling in an alien element."

A director-producer said:

"Sound pictures, that is, with dialog that runs continuously will do away entirely with the art of motion pictures."

Another director said:

"You can't convince me that continuous dialog in a picture will do anything but detract from its value."

One of *the* greatest said:

"I do not believe there is anything revolutionary about the advent of talking pictures."

(It is generally conceded that the advent of sound caused one of the world's greatest revolutionary technological upsets.)

A headline in the *Motion Picture News* where, incidentally, practically all of these quotations appeared says:

"Hollywood is not excited over talkies."

A very prominent chain exhibitor said:

"However, I will never believe that the mechanical reproduction of synchronized music or voice will ever be of any greater value to the industry than just the novelty of it at the beginning."

Our own beloved Thomas A. Edison, I take the liberty of using his name and with the utmost respect and reverence, said:

"I don't think the talking picture will ever be successful in the United States."

And last but not least—here's an Editorial from the *Motion Picture News* of June 2, 1928:

"Furthermore, it is a well-known fact that it is a hard matter to entice members of the New York colony away from Broadway, particularly when they are enjoying favorable salaries."

It makes quite a record. Believe me, please, when I say that I have no desire to ridicule the authors of these statements. They have proved themselves to be keen businessmen and master showmen many times over. The only trouble with their thinking 21 years ago was that the public did not agree with them. They thought they knew what the public wanted—but for once, they missed. To their eternal and everlasting credit, they later reversed themselves, and quickly.

But after it was all over, and everyone had his say, and the Brothers Warner showed them all the way, the editor of the *Motion Picture News* released the following significant statement:

"What after all started this rage that now has the large motion picture industry by the ears? Just one picture, gentlemen, The Jazz Singer. One box-office picture did the trick. That should be borne in mind."

And the editor was right. This fact should indeed be borne in mind, gentlemen. *Because the same thing is going to happen with theater television.* It's only going to take *one* sellout to start the ball rolling. It's only going to take the vision and the courage of *one* man or *one* company to start theater television on its way precisely as *one* company started sound pictures on their way despite the practically unanimous opinion of the industry that it was a foolhardy, silly novelty. There was a wonderful celebration of the Sound Picture's Twentieth Anniversary in August, 1946. Perhaps that in itself should stand as proof that engineers should stick to engineering. I feel sure that if they do, they will always find a group of individuals with enough foresight, imagination, and money to make good use of their inventions.

I am not worried about what any engineer or group of engineers has to say about the commercial future of theater television. Nor am I going to become involved in a discussion of what is the best kind of theater television equipment; direct television which appears on the screen of a theater while the event is actually happening or delayed theater television which is accomplished by practically instantaneous recording on film of both the image and the sound.

But, I am worried about the men who have charge of putting entertainment of one kind or another inside the motion picture theaters of America. English showmen seem to be much more alert to the possibilities of theater television. In 1946 there was present in this country a delegation of six of the executive staff of one of the large British picture companies who also operate many theaters, for the purpose of finding out all we know about theater television. So long as I am connected with the American motion picture industry, it is my aim to keep the subject of theater television constantly in the minds of the American theater owner. I think I can prove that there are enough events of public interest to make theater television a paying proposition to the theater owner. Here is a pretty accurate way of forecasting the answer to this question.

Let us, for instance, take one single, one time-a-year event such as the Kentucky Derby. The racetrack at Churchill Downs in Louisville has a very small capacity, about 65,000. The "sport of kings", however, has a tremendous following scattered throughout the length and breadth of this fair land. Any horseflesh fancier who has ever laid a $2.00 bet on the nose of some "nag" would jump at the opportunity to see the running of the Kentucky Derby. The exhibitors of

America—showmen at heart—will not be slow to visualize this tremendous potential box office. Their programming agency would, I am sure, be able to consummate a deal with the Churchill Downs authorities under whose auspices the race is held whereby, for the payment of a rather substantial sum of money, this event would be telecast exclusively to the theaters of America. In these theaters there are approximately 11,700,000 seats. I daresay that the privilege of witnessing the Derby not from a seat somewhere behind a post, or from the infield without a seat, but from a comfortable chair in one's own neighborhood theater for, let us say, one or even two dollars, would be eagerly accepted.

It would not be a bad seat either, for you can rest assured that the television cameras will be so placed that millions of pairs of eyes in the theaters of America would have a "down-front" seat. As a matter of fact they would have better than a down-front seat. There would undoubtedly be a television camera stationed at each furlong post and the millions of watchers literally would be going around the track with the thoroughbreds. Watching from a theater seat would be infinitely better than from a clubhouse seat at the track. You would hear the frenzied excitement of the crowd, the thundering of hoof beats. You would actually be there without leaving your home town. I feel certain that the Churchill Downs people would be inclined to make this kind of a deal, and I am sure that no sponsor of telecast programs could afford to meet the ante of the exhibitor. This is a roundabout way of my saying that the event would be shown in the theaters only and would not be telecast for home consumption.

Here are a few other events of national interest which would make excellent theater television fare: championship boxing matches, critical major-league end-of-season baseball games, the world series, men's national tennis championships, women's national tennis championships, all important intersectional and many local college and professional football games, basketball games, indoor athletic games, finals of the national horse show, Westminister kennel club finals, national open golf championships, and national bowling championships.

I could go on and on and on. But even then not all the possibilities would be covered, for as the art moves on we shall find additional events possessed of drawing power which do not enter our minds at present. For instance, twenty years ago you would never have

believed that one of radio's most outstanding coast-to-coast stars could be a wooden ventriloquist's dummy. But it is surprising how many people I run into now who said *they* thought so. Hindsight is a very comfortable facesaver.

Objection has been raised to the effect that the inclusion of a theater television program as part of the regular fare of a motion picture theater will interfere with the proper scheduling of a show. I do not fear this. Ways and means will be found to include any event worthy of showing in the theater by rescheduling the show. There need not be much, if any, breaking into the middle of a feature picture in order to show some local happening. That type of event could probably be shown at the end of the picture if the so-called storage method of television were adopted. Nor do I hold with the objection that theaters do not have room for a television projector. Room will be found—if they *need* a hole in the floor they will cut one; if they *need* a larger booth, they will build it.

Then there are those who raise questions regarding possible labor disputes of the jurisdictional type. The picture industry is used to *those* things. Theater television will make it possible for the theater owner to make *his* theater *the* amusement and cultural center of the neighborhood. Think of what that means. Under one roof your patron can have movies, music, current happenings, radio, sporting events, plays, personal appearances, and other interesting programs. Above all it will obviate the necessity of people staying home next to their television sets for fear they will miss something. Some of these events will be charged for, some will be thrown in as part of the show. The main thing is to keep them coming to the theater, the social center of the community.

The purpose of this paper is "let the engineers engineer, and let the showmen worry about the show". Let each man stay within his own calling. Let the engineer believe in his creations and the showman think to a constructive future. I promise you that I will do all I can to keep the showman's mind focused on theater television with a positive attitude. And I shall do everything I can to make it impossible for some future researcher to go to the files and dig out the funny articles and the negative opinions about theater television with which to address the 80th Semiannual Conference of the Society of Motion Picture Engineers.

DISCUSSION

MR. ZIMMERMAN: Mr. Austrian makes a definite point that theater television of special events will be exclusively for theater owners, because their super economic powers can outbid a radio sponsor. Am I correct in that point?

MR. R. B. AUSTRIAN: Yes, I laid the accent on economic power.

MR. ZIMMERMAN: Right now radio and the motion pictures co-operate to a great extent. What will be the economic effect in the motion picture industry, if it begins to buck the broadcast television industry, which is at present, I think we can say, at least a 75 per cent radio operation, rather than a motion picture operation? Are you aware of the implications, or have you gone into that at all in making that particular statement? It is not meant as a challenge, I am just interested.

MR. AUSTRIAN: Yes, I have given some thought to that. I think that the motion picture producer or exhibitor, paradoxical as it may seem, will be one of the greatest customers of the networks. We are going to bring much time on television to put trailers of our pictures in your homes, so that the seesaw will be kept pretty accurate. We may compete with them on events, but also we shall buy a great deal of time. Is that along the lines you were thinking?

MR. ZIMMERMAN: That is one answer. I am just interested whether the large broadcasters feel the pressure of the motion picture people. I think opinion only will be on special events, that is for television broadcasting, as well as theater exhibits.

MR. AUSTRIAN: I think that is right. I have often said without these spontaneous events, games, parades, and so forth, who would want to buy a television set?

MR. L. L. RYDER: I wonder if it would not be well to point out that the air and right to air are not necessarily held entirely by the broadcaster. The broadcaster is not necessarily the televisor. The broadcaster of today is the broadcaster of voice and not necessarily television, because it is a new field we are talking about rather than a competition with an old field.

MR. AUSTRIAN: I think that is true, Mr. Ryder, and our Society has been very forward-looking in having assigned to it certain bands in the spectrum for theater transmission and relay, intercity and intracity. The Telephone Company today has certain bands over which people may speak privately from point to point, or from one point to many points. We consider theater television not broadcasting but a multiple-message service, whether it comes through the air or cables, we do not yet know. All we know is, it is coming.

MR. LANSBERG: First of all, just as an example, we shall transmit football games not only to the home, but also to the theater. That will be a small receiver but we hope to have a larger one available for screen projection in the not too distant future. I believe, also, in the serious work that has been carried on by Paramount Pictures in New York on two different methods of theater television. You can be assured that you are not alone.

MR. AUSTRIAN: Bear in mind, I did not say no one else was doing it, I just said no one else was talking about it.

MR. J. D. BRADLEY: I wonder if you televise through the air, if you can buy an exclusive on an event, if you would be allowed to under the Federal

Communications Rulings? That is the first part of my question. The second part is, it seems to me you are going to have the giants spinning against each other, one to make an exclusive for the theaters, and another to put it in the homes on sponsored programs. It seems to me the attitude of trying to get an exclusive for the theaters is contrary to the present trend of trying to get it in the homes, and represents, perhaps, a justified but selfish attitude.

MR. AUSTRIAN: Well, part one of the question: I do not know what the philosophy of licensing might be at a later date, especially if we approach it from multiple-message service rather than broadcasting. That can change. I do not think we do know the answer. I am looking at it now from possibilities. As to the second part of your question, of course, it will be as everything else is in this world, I guess, in business, a struggle between two people after the same thing. If the man who manufactures tooth paste can pay more for the Kentucky Derby than 17,000 theaters, he will get it, if he can find a way of recouping what he pays for it. However, he does not have a box office and the theaters' financial resources. If what is inside the theater interests you, you pay; and if what is inside does not interest you, you will not pay. So far, the theater men have been very active in putting on something for which a hundred million people —ninety-five million people a week—pay. So there are some large figures there, and if they can outbid the theater and get it, of course, they will.

MISS CATHERINE SIDNEY: Will it be in color or will it be in black and white in the theater?

MR. AUSTRIAN: You are speaking of television—I am sure it will come in black and white first; and I am sure, also, that someday it will also be in color.

MR. JAMES FRANK: I think it should be a matter of record that the Television Practice Committee of this Society has made quite a study of the development as far as it has gone at the present time of theater television equipment. At the present time the efforts of the Committee are at a standstill because we are awaiting a group in the industry to tell us what they want in theater television, how they will use it, and where, and when; and up to the present time I believe it has been impossible to obtain any valid cross section of opinion from the exhibition phase of our industry. So, the Committee and the manufacturers and broadcasters and others represented on that Committee, are to some extent handicapped in their efforts to develop further and to introduce commercially theater television.

MR. AUSTRIAN: Frankly, I do not know as we know what we want. All we know is we want a good, big, bright picture. Now it is up to you to give it to us. Where it comes from, I do not think is too important. Some people expressed a horror at the idea of taking eight or ten or twelve feet out of the front of the balcony. Well, I think you could figure it out with a pencil and paper, if you figured the rate of earning per foot per month, or per year, and plot it against the rate of occupancy of the house, and figure that you can increase your rate of occupancy. Suppose you lose a few seats? You would still take in more dollars. As I said before, if they need a hole in the floor to put in this equipment, they will make it. The main object is, get a machine that will throw an acceptable, clear, bright, large picture.

DR. E. W. KELLOGG: How large a factor do you think it is in the enjoyment of a television program, the fact that you see it absolutely simultaneously with the action *versus* a few minutes' delay?

MR. AUSTRIAN: I can only give you a personal opinion on that as a theater man. I think I should welcome a device upon which I would capture the image and show it to five shows later on in the day, and have that repeat proposition. If you take it as it comes, it is gone forever; but if you can photograph it and perhaps edit it, if you have a few minutes' time you can certainly run it five times, ten times, twenty times, before the newsreels will catch up with you. I think that is very important. So far as its being a few seconds behind, take this audience tonight, for instance—we are all in this room and perhaps there is a football game going on. It is over 30 seconds or 1 minute before we know it. It is news to us. We are isolated. It is just as if it happened. I do not think that would be too great a disadvantage. Also, you can cut in the event at a break in your program between a feature and a short, or between a short and the overture. You get great flexibility and a repeat proposition.

MR. ZIMMERMAN: I have just finished an analysis of replies from all of the theaters of our Army and Navy personnel who have been listening to the playoff games of the National League and the World Series, and we have received a ratio of 5 to 1 of complaints because we rebroadcast the World Series instead of broadcasting it live, even though it was 3:00 o'clock in the morning in Tokyo when they could have received the live broadcast and we rebroadcast it at the earliest possible moment they would be up, namely, 7:00 o'clock in the morning. I think people want to know about events which have a score as to one side or the other as soon as they happen, rather than to wait for some little time. A few seconds would not make any difference.

MR. AUSTRIAN: How do you rebroadcast?

MR. ZIMMERMAN: We rebroadcast them from the network lines. This was purely voice broadcast.

MR. W. H. OFFENHAUSER, JR: Possibly an explanation of that might be that some of the boys had a bet on the game and wanted to pay off their bets as soon as possible.

MR. AUSTRIAN: Some one has already said that theaters could open up pari-mutuel booking offices.

MR. JOHN CRABTREE (dictated to reporter later as a question Mr. Crabtree would like to have printed in the JOURNAL, attention of Mr. Austrian): The chief objection to present-day television images would appear to be lack of sharpness of the screen image. Admittedly in the early days of the sound picture, the sound quality was relatively poor, but the ear will tolerate a wide range in sound quality; but since the eye has been seeing nothing but sharp images since birth, it resents even the slightest lack of definition or sharpness. In my humble opinion, television will not receive widespread adoption until sharper images are available.

DESIGN FACTORS IN 35-MM INTERMITTENT MECHANISMS*

ARTHUR HAYEK**

***Summary.**—The operation of a conventional Geneva-type intermittent mechanism is analyzed and used as a basis for developing several thoughts which may lead to a reduction of pull-down time. Reduction of pull-down time is desirable in that it permits the use of shutter blades of smaller width, thus either increasing the screen brightness or permitting the same screen brightness with less power in the lamp. The increase in the acceleration of the film due to the reduction in the pull-down time naturally will increase the wear and damage to the film. Means are shown, however, whereby the pull-down time may be reduced without subjecting the film to any greater acceleration than occurs with the conventional Geneva-type intermittent mechanism and consequently will not increase the wear on the film.*

Intermittent mechanisms for moving the film, frame by frame, past the projection aperture have been used quite satisfactorily through all the years that motion pictures have been practical. Intermittent mechanisms of the Geneva type are now almost universally used in 35-mm projectors. Other types such as the "Powers" have been used and are worthy of consideration.

This is not being written primarily to describe things which exist but to describe a train of thought which might be followed in an attempt to devise a new intermittent mechanism.

A starting point is always needed, so let us start with an analysis of the Geneva movement, inasmuch as that has been in wide use for a number of years, after which we can develop the above-mentioned line of thought regarding an intermittent movement which would reduce the time of pull-down, increase the efficiency with which we put light on the screen and yet, at the same time, handle the film as easily as at present so as not to reduce the life of the film.

In most projectors the length of the film which is subject to intermittent action is approximately 8 inches. This is the distance from the center of the intermittent sprocket to about 2 inches above the film gate. The weight of an 8-inch length of 35-mm film is approximately 0.0032 pound, so that the mass of the film is therefore

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** General Precision Laboratory, Inc., Pleasantville, N. Y.

approximately 0.0001 slug.* This is the first constant which affects the reasoning described herein and will be considered as having that value in all that follows. Fig. 1A indicates the above-mentioned length of film in relation to the aperture and the intermittent sprocket.

ANALYSIS OF THE GENEVA INTERMITTENT MECHANISM

Fig. 1B indicates the principal relationships involved in the conventional Geneva intermittent mechanism. The radius of the circle on which the pin moves is taken as equal to one. The distance from the point of tangency as the pin enters the slot to the center of the

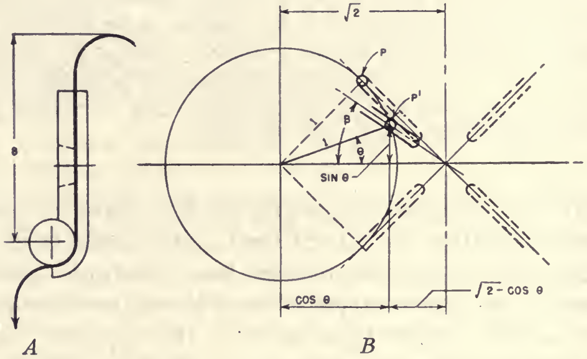


FIG. 1. *A*, Film trap showing approximate length of film subject to intermittent action. *B*, Geneva intermittent.

star wheel is also equal to one. This makes the distance between the centers of the pin shaft and the star wheel equal to $\sqrt{2}$. In connection with this figure, we can develop expressions for the angular displacement or travel of the star wheel, the velocity of the star wheel and the acceleration of the star wheel, all as functions of the angular displacement or travel of the pin.

1. **Angular Displacement or Travel of Star Wheel.**—Let θ represent the angular displacement or travel of the pin and let it be measured from the line connecting the centers of the pin shaft and the star wheel. Let β represent the angular travel or displacement of the star wheel, this angle being measured from the same line.

Then

$$\beta = \tan^{-1} \frac{\sin \theta}{\sqrt{2} - \cos \theta}. \tag{1}$$

* NOTE: Mass in slugs = weight in pounds/acceleration of gravity in feet per second squared. One slug = approximately 32 pounds.

Equation (1) above represents the displacement or travel of the star wheel as a function of the displacement or travel of the pin, both measured from the mid-point of the pull-down period.

2. **Velocity.**—Let ω_p represent the angular velocity of the pin and ω_s represent the angular velocity of the star. Since velocity is the derivative of displacement with respect to time,

$$\omega_s = \frac{d\beta}{dt} \tag{2}$$

$$\omega_p = \frac{d\theta}{dt} \tag{3}$$

and

$$\frac{\omega_s}{\omega_p} = \frac{d\beta}{d\theta} \tag{4}$$

therefore,

$$\omega_s = \omega_p \frac{\sqrt{2}\cos\theta - 1}{3 - 2\sqrt{2}\cos\theta}. \tag{5}$$

Equation (5) is, therefore, the desired equation for the angular velocity of the star as a function of the angular travel or displacement of the pin assuming that the angular velocity of the pin is known.

3. **Acceleration.**—Let α_s represent the acceleration of the star wheel. Since acceleration is the derivative of velocity with respect to time,

$$\alpha_s = \frac{d\omega_s}{dt} \tag{6}$$

and

$$\omega_p = \frac{d\theta}{dt} \tag{3}$$

therefore,

$$\frac{\alpha_s}{\omega_p} = \frac{d\omega_s}{d\theta}. \tag{7}$$

Solving this for α_s we have

$$\alpha_s = \omega_p \frac{d\omega_s}{d\theta} \tag{8}$$

or

$$\alpha_s = \omega_p^2 \frac{\sqrt{2}\sin\theta}{(3 - 2\sqrt{2}\cos\theta)^2}. \tag{9}$$

Equation (9) is the equation for acceleration of the star wheel as a function of the angular travel or displacement of the pin assuming that the angular velocity of the pin is known.

Equations (1), (5), and (9) show the basic behavior of the Geneva intermittent mechanism itself. To obtain information regarding the film which is controlled or moved by the intermittent mechanism let us express β, ω_s, and α_s in radians and the radius R of the intermittent sprocket in inches. Let s represent the travel or displacement of the film in inches per second and let a represent the acceleration of the films in inches per second per second.

Then

$$s = R\beta \tag{10}$$

$$v = R\omega_s \tag{11}$$

and

$$a = R\alpha_s. \tag{12}$$

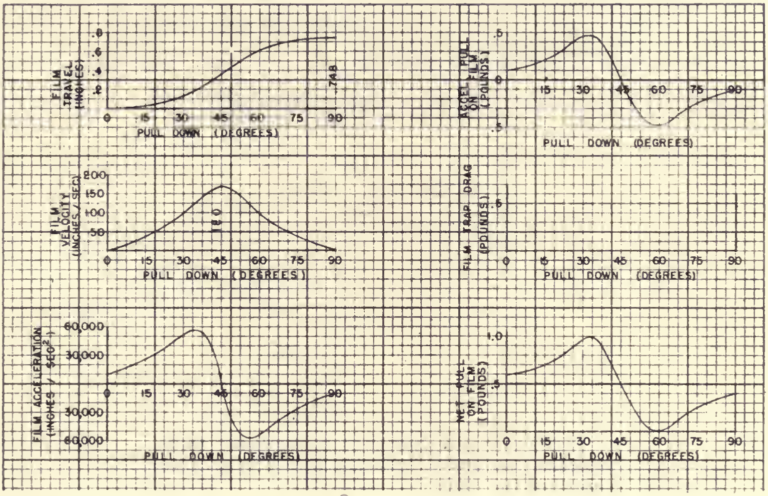
Equations (10), (11), and (12) give the travel, velocity, and acceleration characteristics of the film as a function of the comparable characteristics of the intermittent mechanism for any position of the pin measured in radians from the mid-point of the pull-down period.

While the equations given above show travel velocity and acceleration as a function of angular displacement from the mid-point of the pull-down period, it is easier to visualize the result if the curves corresponding to the equations are plotted with the abscissa expressed as degrees and with zero at the starting point of the pull-down period. All of the curves which follow are consistent with the above and the number of degrees correspond to the angular displacement of the pin shaft or equivalent mechanism which is assumed to operate the intermittent mechanism once per revolution and which rotates at 1440 revolutions per minute (24 frames per second).

The three curves of Fig. 2A show the characteristics pertaining to film driven by the Geneva intermittent mechanism. The upper curve indicates film travel, the middle one film velocity, and the lower one film acceleration, all as a function of the angular rotation of the pin shaft. From the upper curve it is seen that only a very small movement of the film occurs during the first few and the last few degrees of the pull-down. Actually, in the first eight degrees the film is moved only 0.005 inch with a like movement occurring during the last eight degrees. Inspection of the middle curve shows that the maximum velocity of the film is reached at the mid-point of the pull-down period and attains a value of approximately 180 inches per second, which is

about ten times the average speed of the film through the projector. The lower curve shows that the film is accelerated for the first half of the pull-down. The maximum acceleration or deceleration is approximately 60,000 inches per second per second.

The curves of Fig. 2B show characteristics which are related particularly to tension on the film when driven by a Geneva movement. The upper curve shows the pull on the film caused by its acceleration which is determined by the movement of the intermittent mechanism.



A *B*

FIG. 2. *A*, Travel, velocity, and acceleration of the film. *B*, Pull on the film caused by acceleration and film-trap drag.

This pull is determined by multiplying the film-acceleration curve by the mass of the film, the determination of which was described earlier. In addition to the accelerating pull on the film imposed upon it by the intermittent mechanism there is an additional stress due to the friction in the film gate. At the mid-point of the pull-down period the film is traveling at 180 inches per second and if no means were provided to decelerate it, it would tend to continue this speed and would try to overshoot the intermittent sprocket. In order that the film will never tend to overshoot and will come to rest precisely under the control of the intermittent mechanism the film-trap drag must be at least equal to the peak inertia force on the film at its peak point of deceleration, which is approximately 0.5 pound. The middle curve,

therefore, shows this additional film-trap drag. Experimental evidence confirms this value at least well enough to justify its use in a discussion of this kind. The lower curve shows the net pull on the film caused by its acceleration by the intermittent mechanism as shown in the upper curve and the film-trap drag as shown in the middle curve.

During the first half of the pull-down the force on the film caused by acceleration and film-trap drag act in the same direction and must be added. During the last half of the pull-down they act in opposite directions and must be subtracted. As previously indicated, the net

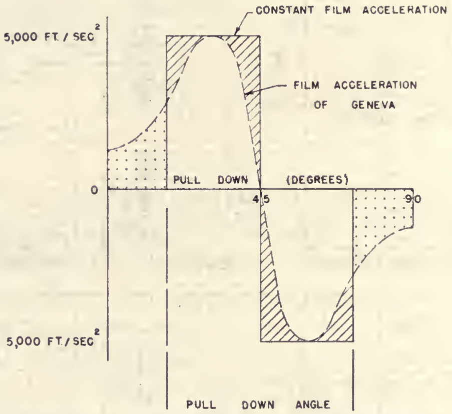


FIG. 3. Comparison of a constant film-acceleration curve with the film-acceleration curve of the Geneva.

pull on the film should never be negative if a steady picture is to be achieved. Inspection of the curve shows that the film, is subject to its greatest stress during the first half of the pull-down, that this point occurs at the point of maximum film acceleration, and that the net pull on the film is approximately one pound.

The thoughts which follow are developed on the assumption that if the net pull on the film is not allowed to exceed this value of one pound, no more damage will be done to the film by other intermittent mechanisms than by the Geneva movement and this has been the controlling factor in the train of thought which follows.

1. *Constant Film Acceleration and Deceleration.*—Let us now take our first step toward the synthesis of an intermittent mechanism which will have an operating period of less than the 90-degree period of the Geneva movement. Let us see what would be the result if we could make an intermittent mechanism, which in association with the

present type of film trap would give the film constant acceleration during the first half of the pull-down and constant deceleration during the last half of the pull-down and yet would not impose a net pull of more than one pound on the film.

Let the film be given a constant acceleration of 5000 feet per second per second, the same as the peak acceleration of the Geneva. Then the acceleration curve of the film as compared with that of the Geneva would be as shown in Fig. 3. It can be seen from Fig. 3 that giving the

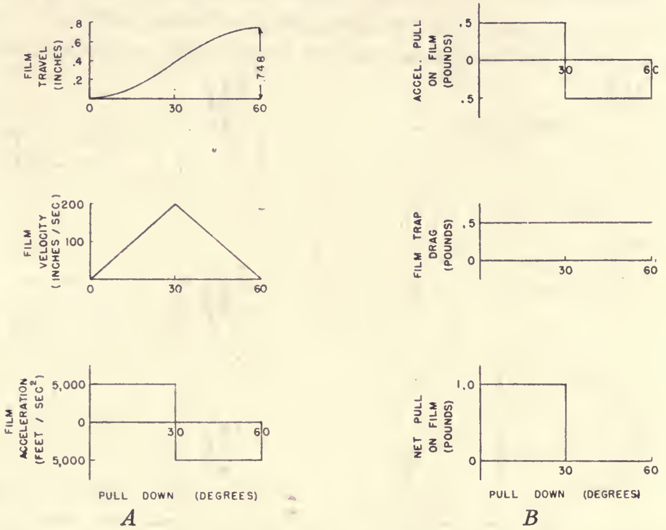


FIG. 4. *A*, Travel, velocity, and acceleration of the film. *B*, Pull on the film caused by acceleration and film-trap drag.

film constant acceleration amounts to chopping off the dotted portion of the Geneva acceleration curve and using it to fill in the cross-hatched portion of the constant film-acceleration curve. The pull-down angle is thus reduced and since the maximum acceleration of the film has not been increased there is no increase in the stress on the film. The reduction in the pull-down angle can be computed from the equation

$$S = {}^1/_2\, at^2$$

where $S = \dfrac{0.748}{2} = {}^1/_2$ the height of a frame of film

$$a = 5000 \text{ ft/sec}^2 \text{ or } 60{,}000 \text{ in./sec}^2$$

$$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 0.748/2}{60{,}000}} = 0.0035 \text{ sec}$$

$$\theta/2 = 360 \times \frac{0.0035}{1/24} = 30°$$

$$\theta = 60° \text{ pull-down angle.}$$

The film travel, velocity, and acceleration curves are shown in Fig. 4A. The forces on the film due to its acceleration and film-trap drag and the resulting net force on the film are shown in Fig. 4B. It can be seen that although the pull-down time is reduced, the net pull on the film is still the same as that of the Geneva.

2. *Variable Film-Trap Drag.*—Another possible way to reduce the pull-down angle is to vary the film-trap drag. The only purpose of the film-trap drag is to decelerate the film during the last half of

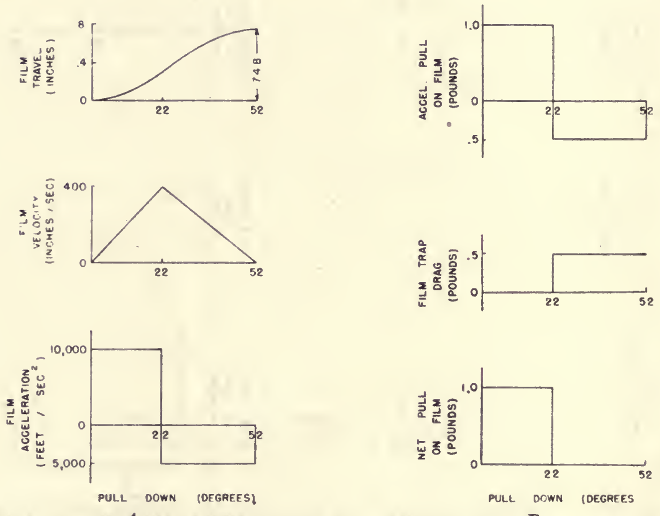


FIG. 5. *A*, Travel, velocity, and acceleration of the film. *B*, Pull on the film caused by acceleration and film-trap drag.

the pull-down. It is not needed during the first half of the pull-down when all it does is hinder the acceleration of the film. It would, therefore, be desirable to have film-trap drag only during the last half of the pull-down. This might be accomplished by means of an electromagnet which would release the pressure of the film gate during the first half of the pull-down.

If this could be done, then during the first half of the pull-down, the pull on the film would be only that due to its acceleration alone ($^1/_2$ pound). Since we are allowing a maximum pull on the film of one pound, the pull on the film due to acceleration alone could be doubled and its acceleration increased from 5000 to 10,000 feet per second

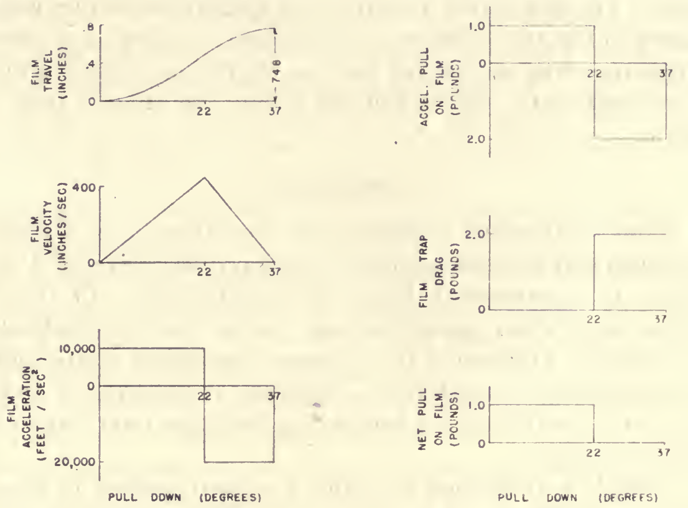
squared. This would permit the time for the first half of the pull-down to be reduced to

$$s = {}^1/_2\, at^2$$

$$t = \frac{2s}{a} = \frac{2 \times 0.0748/2}{10{,}000 \times 12 \text{ in.}} = 0.0026 \text{ sec}$$

$$\theta/2 = \frac{0.0026}{1/24} \times 360 = 22°.$$

The total pull-down angle would take place in 22 + 30 degrees = 52 degrees. The film travel, velocity, and acceleration curves would be as shown in Fig. 5A. The forces on the film caused by its acceleration



A *B*

FIG. 6. *A*, Travel, velocity, and acceleration of the film. *B*, Pull on the film caused by acceleration and film-trap drag.

and the film-trap drag and the net force on the film are shown in Fig. 5B. It can be seen that the net force on the film is still no higher than one pound, the maximum pull on the film with the Geneva.

3. *Rapid Deceleration of the Film.*—A third possible way to reduce the pull-down time is to increase the deceleration of the film. During the last half of the pull-down, the forces on the film and the film-trap drag act in opposite directions so that if they are of equal magnitude the net force on the film is zero. If the deceleration of the film were increased from 5000 feet per second to 20,000 feet per second squared,

the deceleration force of the film would be increased from $^1/_2$ to 2 pounds. Then if the film-trap drag were increased from $^1/_2$ to 2 pounds, the net force on the film would be zero. If it is assumed that the deceleration of the film were 20,000 feet per second squared, the time for the last half of the pull down could be reduced to

$$s = {}^1/_2\, at^2$$

$$t = \frac{2s}{a} = \frac{2 \times .0748/2}{20{,}000 \times 12} = 0.000177 \text{ sec}$$

$$\theta = \frac{0.00177}{1/24} \times 360 = 15°.$$

The time for the full pull-down would thus be 22 + 15 degrees = 37 degrees. The film travel, velocity, and acceleration curves would be as shown in Fig. 6A. The force on the film caused by its acceleration and film-trap drag and the net force on the film are shown in Fig. 6B. The net pull on the film is still one pound, the same as that of the Geneva.

CONCLUSIONS

A series of thoughts regarding the operation of an intermittent mechanism and its associated film trap have been developed, as preliminary to experimental design and construction. Of the above only the Geneva movement has been used or built in practical commercial form. The cam of the "Powers" movement is susceptible to design so as to give constant acceleration and deceleration and some experimental work has been done with a 60-degree intermittent mechanism of this type.

It should be reaffirmed that this has been written to report on thoughts, not things, and to provoke interest in the development and use of intermittent mechanisms which will give a shorter pull-down time and which will thereby increase the efficiency with which light is put upon the screen.

ACKNOWLEDGMENT

The author wishes to acknowledge his indebtedness to Mr. G. T. Lorance for his presentation of the paper at the SMPE convention and for his many suggestions and help in the preparation of this paper.

LIGHTWEIGHT RECORDERS FOR 35- AND 16-MM FILM*

M. E. COLLINS**

***Summary.**—Recorders have been designed to provide the motion picture industry with improved lightweight recording machines capable of recording any of the standard types of negative or direct positive sound tracks. Separate recorders have been designed for use with 35- and 16-mm film, each recorder being designed for optimum performance with the film for which it was designed. Chief features of the recorders are improved performance, dependable operation, compactness, minimum weight, and accessibility for servicing, combined with attractive styling. The recorders have been designed so that the film may be driven from left to right or from right to left through the head assembly with equal stability. An automatic film take-up mechanism of the self-reversing type is provided.*

The PR-32 16-mm recorder and the PR-33 35-mm recorder have been designed to provide the motion picture industry improved lightweight recording machines capable of recording any of the standard types of negative or direct positive sound tracks. Chief features of the design are improved performance, dependable operation, compactness, lightness of weight, and accessibility for servicing.

The two recorders are identical in design and construction except for the difference in the film-handling rollers and sprocket, the take-up assembly, the film magazines, and the drive-chain reduction ratio.

In designing these recorders it was decided that separate recorders should be provided for 16- and for 35-mm recording rather than one machine should be designed that was intended to be converted for use with either type of film. The basis for the decision was the fact that each recorder could then be designed without the necessity of making compromises which might affect the performance of the entire machine.

For purposes of economy and simplification of replacement parts, the two recorders were designed with as high a percentage of identical parts as possible without resorting to undesirable design compromises.

The recorder (Fig. 1) consists of the following units or subassemblies:

(A) A base assembly containing the plugs, lamp rheostat, reversing switch, and recesses that form the handles for carrying.

(B) A head assembly containing all of the gearing and film-handling equipment.

(C) An optical system.

(D) A driving motor, single or 3-phase synchronous, alternating- or direct-current interlock.

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* Presented Apr. 24, 1947, at the SMPE Convention in Chicago.

** Radio Corporation of America, Hollywood 38, Calif.

(E) A take-up assembly, beltless reversible or belt-drive type.

(F) A control-panel assembly containing rheostat adjustment, recording-lamp ammeter, footage counter, and switches for motor, lamp, and modulation.

(G) Covers for the optical system, motor compartment, and gear compartment.

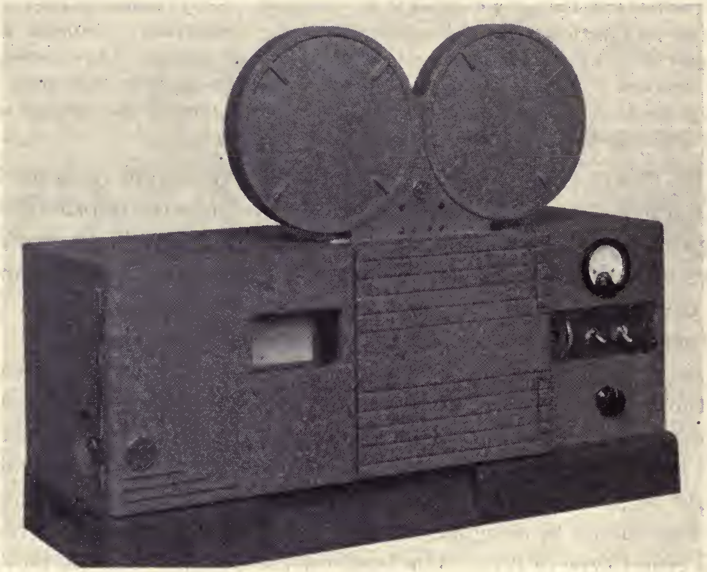

FIG. 1. PR-32 16-mm recorder.

The 35-mm recorder is $23^3/_4$ inches long, 9 inches deep, and $21^1/_4$ inches high, with the magazine in place, and weighs approximately 85 pounds. The magazine is the 1000-foot Bell and Howell type. Other type magazines could be used with a suitable magazine spacer.

The 16-mm recorder has the same base dimension, but is 18 inches high with the 400-foot RCA magazine in place and weighs approximately 75 pounds. The RCA 16-mm 400-foot recording magazine is of new design using roller-type light traps and pulleys of such construction that the take-up side may either be belt-driven or driven by an engaging pin located in the take-up drive assembly.

The recorders have been attractively styled and all parts have been finished to provide maximum protection against rust and corrosion. The recorder base is finished deep umber gray metaluster wrinkle and

the units above the base are finished light umber gray metaluster wrinkle. The film compartment is finished light umber gray enamel.

Fig. 2 shows the base assembly containing the connection plugs, the lamp rheostat, the modulation transformer, wiring, terminal board, and built-in carrying recess. The bottom of the base is tapped in each corner so that the recorder may be bolted in place if required.

A continuously variable carbon pile-type rheostat is used to provide smooth, stepless lamp control. A two-to-one stepdown control of the rheostat is provided to simplify making fine lamp-current adjustments.

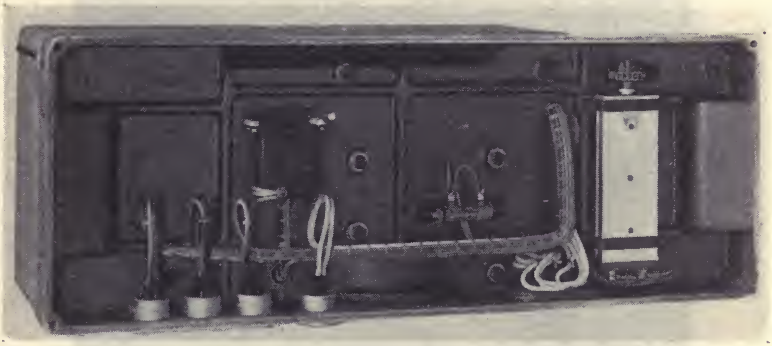

FIG. 2. PR-32/PR-33 base assembly.

The base casting is made of stabilized magnesium, as are all of the structural castings of both recorders. All castings are given a dichromate treatment before applying the organic finish. This assures maximum casting protection and provides excellent adhesion for the organic finish.

The head assembly (Fig. 3) contains all of the film-handling and driving equipment except the motor and one silent chain sprocket attached to the motor shaft. A step-cut-type light seal is employed between the film compartment and its door. A positive-type door latch of simple construction and easy operation is located in the bottom edge of the door. A vertical casting wall divides the film compartment from the drive equipment.

The film drive of the 35-mm machine consists of a drumshaft and flywheel assembly mounted on precision ball bearings, one undamped sprung roller assembly, one damped sprung roller assembly, and the necessary sprocket-pad roller assemblies. The sprung rollers are provided with positive stops to limit their travel, prevent spring damage, and to assure uniform threading loops. Threading is done with

one roller assembly in its normal position as held by the associated spring, and with the other roller assembly held against its stop opposing the spring action. The sprung rollers are made of anodized aluminum fitted with precision sleeve bearings. The roller arms are exceptionally light in weight and are pivoted on precision ball bearings.

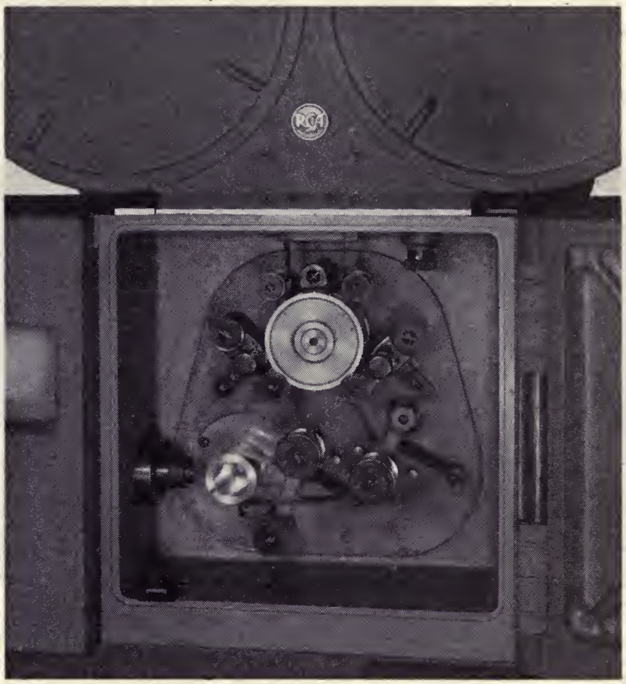

FIG. 3. PR-32 head assembly.

The pad rollers are held in position against the sprocket by positive detents and are held open for threading by spring action. Clearance between the pad rollers and the sprockets is controlled by a detent plate provided with a simple screw-driver adjustment.

The recording drum is film-pulled and coupled through its shaft to a solid, dynamically balanced flywheel. The sprung rollers are flanged to provide the necessary lateral film guiding.

Threading is very simple and the design is such as to provide the same length of film loop each time the machine is threaded.

The necessary damping is provided by an air-type dashpot coupled to the right-hand sprung roller. The design of the dashpot is such that no adjustments are required.

The film drive of the 16-mm recorder is identical to that of the 35-mm recorder except for the changes required to handle the narrower film and changes in the flywheel inertia and dashpot so as to provide optimum motion steadiness at the reduced film speed.

The film-handling equipment and the gearing have been designed

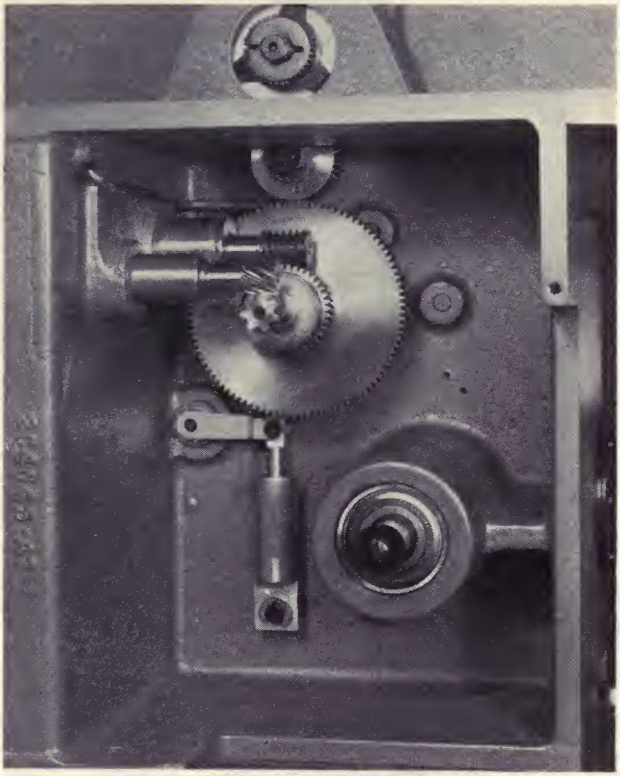

FIG. 4. PR-32/PR-33 recorder head, drive side (flywheel removed).

so that the film may be driven from left to right or from right to left through the recorder with equal stability.

The film-drive mechanism (Fig. 4) consists of a motor mounted on the base assembly and coupled to the recorder drive shaft by precision chain sprockets and a $^3/_{16}$-inch pitch silent chain, and simplified precision helical gearing located in the head assembly. The main drive shaft drives the sprocket and the take-up assembly through

precision-cut right-angle helical gears. A right-angle helical drive from the sprocket shaft and a ladder chain are provided to drive the footage counter. Changes in reduction ratio as required for different frequencies and different motor speeds are accomplished with both re-

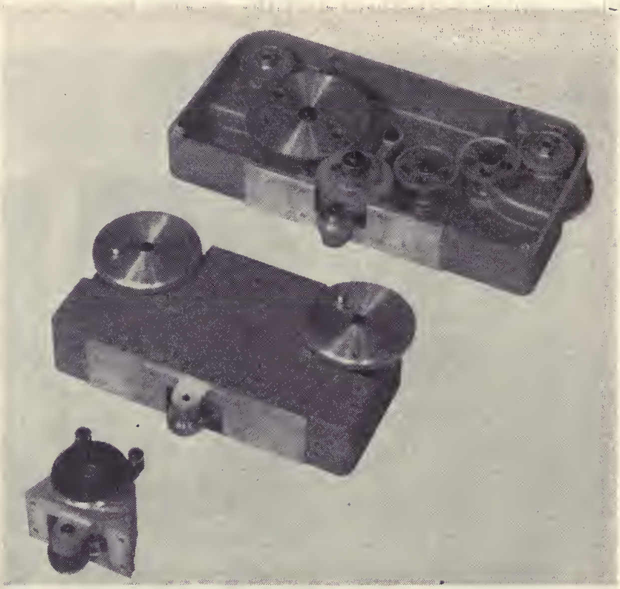

FIG. 5. PR-32/PR-33 magazine-drive units.

corders by changing the silent chain sprockets and the silent chain. One set of head gearing is used for all applications for both 16- and 35-mm recorders.

Fig. 5 shows a beltless reversible-type take-up assembly provided for both recorders. This take-up assembly is gear-driven from the head and is provided with a thrust-mesh arrangement so that either side of the mechanism may be driven. When the recorder sprocket is driven counterclockwise, the right-hand side of the take-up assembly is driven and the left side acts as a holdback mechanism. When the recorder is reversed and the sprocket is driven clockwise, the take-up thrust-gear mechanism reverses and the left side of the take-up becomes the driven side.

A belt-type take-up is provided as optional equipment and is designed to mount interchangeably with the beltless take-up. With this take-up it is necessary to move the belt manually to the proper magazine pulley when the recorder direction is reversed.

The optical-system compartment (Fig. 6) is provided with a hinged door through which all normal operating adjustments are made to the optical system except for galvanometer tilting, which is done without opening the door, by an adjusting screw accessible from the left end of the optical-system cover. The complete optical-system housing is removable by loosening two knurled thumbscrews located in the

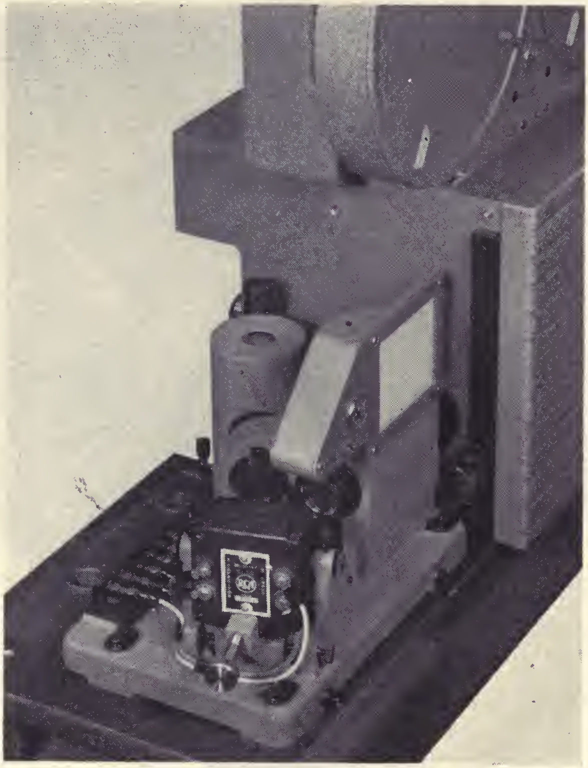

FIG. 6. PR-32/PR-33 optical-system compartment (housing removed).

compartment. The optical-system door is equipped with an opening for observing the visual monitor.

The housing (Fig. 7) covering the back of the control panel and the motor compartment is removable by loosening two screws located in the end of the housing. This cover is provided with a recess for a flush-type handwheel mounted on the motor shaft. When the motor-

compartment cover has been removed, the motor, drive chain and sprockets, footage counter and drive, rheostat control, terminal board, and all switches are readily accessible.

Both recorders may be provided with single-phase 115-volt synchronous motors, 230-volt, 3-phase synchronous motors, alternating-current interlock (Selsyn) motor, or multiduty (direct-current inter-

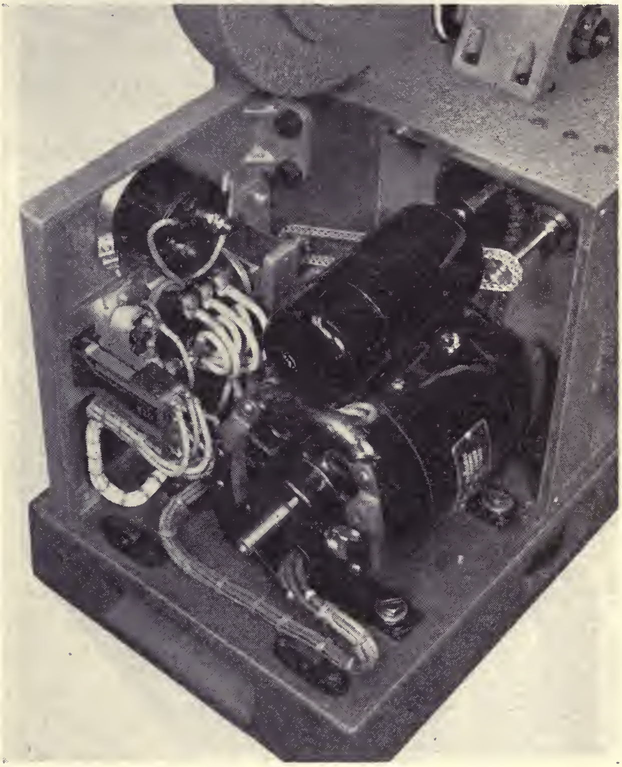

FIG. 7. PR-32/PR-33 motor and control compartment (housing removed).

lock) motors; however, the 16-mm recorder normally will be supplied with a single-phase, 115-volt synchronous motor. In order to keep vibration and noise to a minimum, all motors used are statically and dynamically balanced and are resilience-mounted to the recorder base. The motor is provided with sufficient lateral adjustment to assure proper tension of the drive chain and to compensate for any possible increase in length of chain after considerable service.

The cover plate over the gear compartment is easily removed for inspection or service. When the cover has been removed, the flywheel, dashpot assembly, and all gearing are readily accessible.

The optical systems (Fig. 8), which have been especially designed for these recorders, provide rear-projection visual monitoring of an improved type. The visual monitor adjustments have been greatly simplified and the monitoring screen, as well all mechanical and optical parts of the monitor, is mounted to the optical-system casting. The monitoring screen and mirror assembly are removed as a unit from the optical system when focusing the system or when it is desired to remove or insert the ultraviolet filter. Since the monitoring screen and mirror assembly is doweled in place, it can be removed and reassembled on the system without disturbing any adjustments. The optical system used for 35-mm recording and the system used for 16-mm recording are identical except for the dimensions of the recording slits and apertures. The optical system has been designed to provide a maximum of hand room while compactness is retained. The recording lamp is a prefocused base, 10.5-volt, 7.8-ampere, curved, coiled-filament lamp. An improved lamp socket, providing the necessary vernier adjustments, is used, as is also an improved modulator,

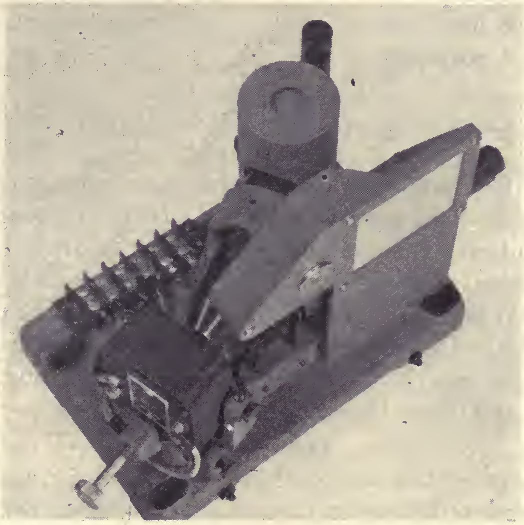

FIG. 8. PR-32/PR-33 optical system.

exceptionally sturdy and reliable. The area-type optical system is standard with both recorders; normally it is provided to produce a biased-type standard track. Both optical systems provide for standard negative recording, direct positive recording, or reversal-type track without requiring any modification or adjustments to the system, except for tilting the modulator. A focusing microscope is provided for both optical systems. The microscope is inserted in the recording drum and provides a very useful operating and inspection tool. The optical systems are extremely flexible in application and may be supplied for any of the listed types of recording:

(A) Standard area
(B) Class B push-pull
(C) Class A push-pull
(D) Class AB push-pull
(E) Double-width recording (35-mm system only)
(F) Direct positive

If desired, a variable-intensity-type optical system can be provided.

PERFORMANCE

Studies of film motion made by flutter measurements on both the 16- and 35-mm model recorders indicate that the performance of the machines will compare very favorably with lightweight recorders available to date. The total flutter for all frequency bands is approximately ± 0.05 per cent. The sprocket-hole frequency disturbances have been reduced to a negligible value. The low-frequency disturbances have been kept to a minimum by careful designing of the filter components and film-drive equipment.

CONCLUSION

In the design of these recorders every consideration has been given to the problems of operation, maintenance, compactness, and sturdiness. All parts have been amply designed so as to insure reliability and at the same time the weight and bulk have been kept to a minimum. Adjustments have been eliminated wherever possible and the necessary adjustments, which have been retained, are simple to make and easily accessible.

The same high degree of accuracy and precision is used in making the parts of these recorders as is employed in the manufacture of parts for the Type PR-31 De Luxe Film Recorder. Selective assembly is not tolerated and all components are held to close tolerances to assure interchangeability of parts and optimum performance.

It is our belief that the PR-32 16-mm recorder and the PR-33 35-mm recorder will completely satisfy the requirements for high-quality, lightweight recording machines.

A PHOTOELECTRIC METHOD FOR DETERMINING COLOR BALANCE OF 16-MM KODACHROME DUPLICATING PRINTERS*

PAUL S. AEX**

Summary.—*It has been necessary in the past to control the color balance and exposure of 16-mm duplicating printers by making actual test prints at frequent intervals. A large amount of footage could be risked during the time required for processing the test prints. A method is described by which it is possible to check the balance of the printer instantly by means of tricolor readings with a photronic cell.*

The printing of 16-mm Kodachrome duplicates on available motion picture printing equipment involves many problems which make this operation considerably more complex than the printing of black-and-white film on the same equipment. In black-and-white work, density alone has to be controlled in printing, while in making Kodachrome duplicates, both density and color balance must be controlled.

This control must be very accurate, since small changes in color are more noticeable than similar small changes in black-and-white. Density control in black-and-white printing can be accomplished by aperture changes or, more conveniently, by changes in lamp voltage. However, in Kodachrome duplicating, density must be controlled by aperture only, or by the use of neutral-density filters, since voltage changes will affect color balance.

Color balance in this work is controlled by the use of gelatin color-compensating filters. These are cyan, magenta, and yellow filters available in several small color-density steps. The color-balancing of the printer is accomplished by adding or subtracting combinations of these filters until the desired balance is obtained on the print.

In setting up a printer for black-and-white printing it is only necessary to make a range of exposures on the stock to be used and to pick the proper exposure by density measurements from the resulting prints. The setting up of a printer for Kodachrome duplicating, however, is more difficult. The lamp voltage first must be adjusted to

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* Presented Apr. 22, 1947, at the SMPE Convention in Chicago.

** Eastman Kodak Company, Kodak Park Works, Cine Kodak Processing Department, Rochester, N. Y.

give a color temperature and lamp brightness which will make a satisfactory balance possible. The proper exposure range can then be determined by a series of flash tests or actual prints, the actual exposure changes being made by aperture or by additions of neutral-density filters, so as not to change the color temperature. After this has been done it is necessary to start out with some basic filter combination and to make a series of tests, adding or subtracting color-compensating filters, until a neutral balance is obtained. This usually entails printing a number of actual tests on the Kodachrome duplicating stock. Specific instructions for the procedure are contained in the manual "Instructions for Making 16-Mm Kodachrome Duplicates on Kodachrome Duplicating Film, Type 5265", which may be obtained from the Motion Picture Film Department of the Eastman Kodak Company. If several printers are to be used, it is at present necessary to go through the procedure described, to balance each one.

After a printer has been satisfactorily balanced to make 16-mm Kodachrome duplicates, it must be checked periodically to ensure keeping it in balance. This requires a constant check on the quality of the production work printed, and also the making of test prints for the specific purpose of a critical check on color balance and density.

This method of checking color balance and density on Kodachrome duplicating printers is necessarily time-consuming. The problem is especially serious when the printer is located at some distance from the processing laboratory. Since it is generally necessary to keep the printer operating continuously, the delay involved in the transportation of the work to and from processing may necessitate the risk of a considerable amount of footage before the results of tests or current production can be seen. If the quality of the finished work, or the tests indicate that the printer is off-balance, further filter changes and tests must be carried out and additional delay is encountered.

Because of these problems there has long been a need for some simple and rapid method to check Kodachrome duplicating printers. An instrument has been devised recently which will provide an accurate and almost instantaneous test of both color balance and exposure on such printing equipment.

The instrument consists essentially of a photocell and a sensitive galvanometer arranged so that light-readings can be made at the printer aperture through red, green, and blue filters. These readings are an indication of both color quality and exposure. Such an instrument is illustrated in Fig. 1.

As pictured, the instrument has been constructed for use with a 16-mm Depue continuous printer. Variations, however, could be made for use with almost any type of 16-mm printing equipment. The photocell housing in this case has been shaped to fit snugly over the gate and aperture of the Depue printer so that stray light is eliminated. The aperture of the photocell housing has been made to exactly the same size as the printer aperture and the housing is designed to fit in place in only one position, so that the aperture of the printer and that of the photocell will coincide.

In order to minimize the effects of cell fatigue and consequent error, it has been found necessary to distribute the light striking the photocell evenly over the entire cell surface. In this particular case, the

FIG. 1. Photocell head and galvanometer.

limited amount of space available at the gate of the Depue printer makes this difficult, but the method by which it is accomplished is shown in the drawing of the photocell housing, Fig. 2.

The light entering the aperture *A* is gathered up by a Lucite rod *B* and is conducted to the cell *C*. The end of the lucite rod *D* is rounded and the surface has been ground so that it projects the light evenly over the entire surface of the cell. A sliding carrier *E* holding the red, blue, and green filters is located between the rounded end of the rod and the cell. In this way the three-color readings can be made simply by sliding the carrier so as to place first the blue, then the green, and finally the red filter in the beam.

The photocell used in this case is an Electrocell No. 2, regular type, 2 inches in diameter. The sensitivity curve for this cell is very similar, however, to a Weston Photronic cell, Type III, and it is planned eventually to substitute the Type III for the present one.

The cell is connected to the galvanometer by a shielded lead to prevent errors from outside electrical disturbances. The galvanometer* used is equipped with an adjustment for zero setting and has a scale reading from 0 to 80. A sensitive galvanometer of this type is necessary in order to get sufficient accuracy because of the small light intensities measured, and consequent small currents generated by the cell. This particular combination of Electrocell and galvanometer has proved to be extremely sensitive to light of low intensity such as is encountered in making printer measurements. Although the G. M. galvanometer is a very sensitive instrument, it has proved to be satisfactorily resistant to disturbance and shock resulting from reasonably careful handling.

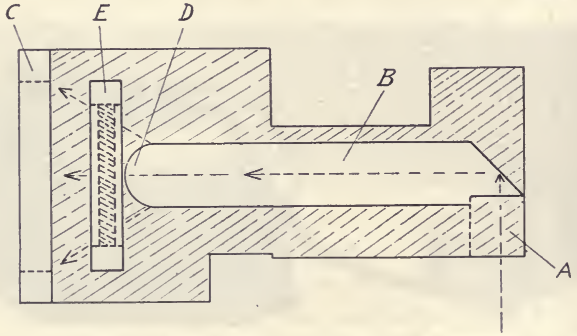

FIG. 2. Enlarged view of photocell head.

The tricolor filters chosen for use with this instrument are the Wratten No. 47 blue, No. 53 green, and No. 29 red. These filters in combination with the Electrocell give sensitivity peaks in the blue, green, and red portions of the spectrum which correspond to the critical sensitivities of the Kodachrome duplicating film. Readings made at the printer aperture, therefore, indicate the relative intensities of the blue, green, and red components of the printer light. Proper adjustment of these intensities by use of the color-compensating filters in the printer will result in a neutral balance on the Kodachrome film. The instrument is sensitive enough to record a substantial change in reading when the most dilute color-compensating filters are added or subtracted from the printer. It will also record a one-sixth-stop change in exposure.

* G. M. mirror type, Serial No. 9640, Catalog No. 11026, G. M. Laboratories, Inc., Chicago, Ill.

The instrument in use on a printer is shown in Fig. 3. Before locating the photocell housing on the printer, the galvanometer should be adjusted to zero. The printer lamp previously should have been turned on and allowed to burn for about two minutes. This permits the lamp to come to equilibrium. The printer aperture should be set at the normal opening for printing from normally exposed originals. The aperture of the photocell housing is then located over the

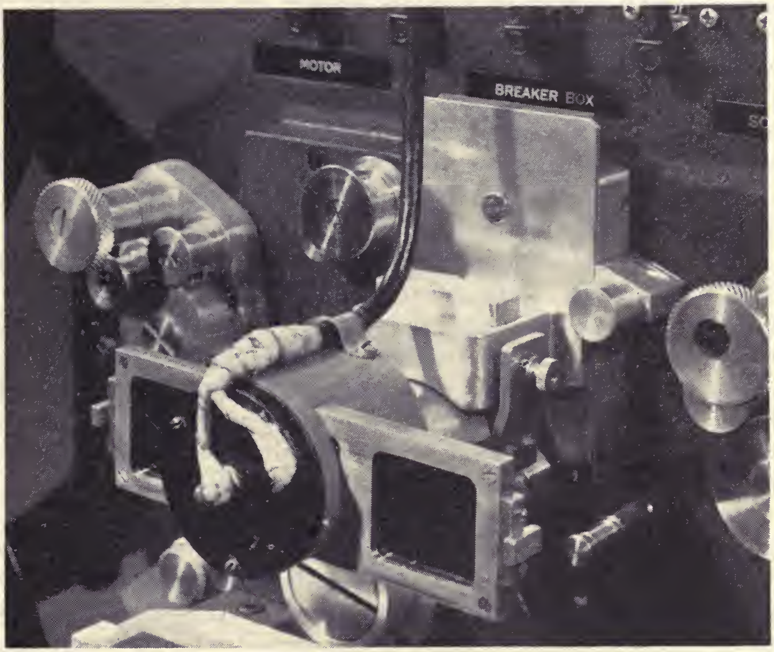

FIG. 3. Photocell head on printer.

aperture of the printer and the cell is clamped securely in place. The location of the photocell housing on the printer, as shown, is facilitated by a pair of stops on the housing which ensure accurate alignment of the two apertures. When the cell is in place, the blue filter is placed in the beam and the galvanometer reading is taken. The green filter reading is taken next, and then the red.

In order to use the instrument properly, one printer must first be balanced to give a neutral color balance and correct density on the Kodachrome duplicating film by photographic tests, as has been

previously described. Once this has been done, however, and tricolor readings taken with the instrument, these readings may be used as a standard. Additional printers of the same type may then be balanced simply by comparing the new printer with the instrument and by bringing the readings to match the standard.

When the printers have been balanced and are in production, they may be checked periodically with the instrument, thereby giving an instant check on the quality of the production work. If this check indicates that a printer is out of balance, it may immediately be brought back to standard by making the necessary printer changes. To facilitate this it has been found desirable to compile tables showing the changes in tricolor readings caused by the addition or subtraction of individual color-compensating filters to the printer. Similar tables have been made for exposure changes. In this way, when an off-standard reading is obtained, the proper corrections can immediately be calculated and applied.

Individual emulsion numbers of Kodachrome Duplicating Film, Type 5265, may require slightly different balances. When a new emulsion number is to be used, one printer will have to be balanced by a photographic test and a new standard reading for this emulsion determined. This, of course, is simplified by the information given on the film carton concerning the filter change required for the emulsion batch. When the new standard reading is obtained the other printers may be changed over to the new emulsion by use of the instrument.

Under actual production conditions the instrument has proved to be an extremely valuable aid in the control of 16-mm Kodachrome duplicating printers. In several cases when used for setting up new printers it has given a satisfactory balance on the first test. Compared to the numerous tests required to balance a printer by strictly photographic methods this represents a considerable saving in time and effort. The instrument has been used for some time for the control of several 16-mm Depue printers engaged in continuous production of Kodachrome duplicating work. In this operation it has provided an accurate, instant check on color balance and exposure, and has eliminated the use of daily photographic printer tests. Thus, it has saved time, lowered waste, and reduced cost.

PORTABLE AND SEMIPORTABLE LOUDSPEAKER SYSTEMS FOR REPRODUCING 16-MM SOUND ON FILM*

JOHN K. HILLIARD**

Summary—*This paper describes three types of loudspeaker systems which have been designed for 16-mm sound on film reproduction. One system uses a dia-cone speaker mounted in a portable leatherette carrying case. A 12-inch speaker is used and the acoustic radiation is obtained from two diaphragms attached to a single voice coil. The outer diaphragm is of the molded-cone type and the inner is a domed dural type of diaphragm which is attached at its edges to the 3-inch voice coil. A second system is mounted in a portable cabinet which has 3.2 cubic feet and is resonated for maximum response down to 85 cycles. The speaker is of the 15-inch type and of similar construction to the 12-inch with the addition of a 6-cell multicellular horn mounted directly in front of the 3-inch dural diaphragm. The third system consists of a duplex speaker and is intended for permanent and semipermanent installations.*

The widespread application of 16-mm sound on film in the entertainment, educational, and industrial fields has created demands for higher quality. In the past, quality has been limited by various factors such as flutter content, size of the image in relation to the slit, inadequate power-amplifier output, and inefficient limited-range loudspeakers.

This paper describes three types of loudspeakers which are designed to utilize more fully the new improvements in 16-mm projectors which shortly will be made available.

The principal limitations in 16-mm loudspeakers are caused by the low efficiency, lack of uniform distribution over a wide angle, inadequate frequency range, and high distortion at operating levels. Three different types of units are available varying in size and weight for portable and semiportable installations, which minimize these deficiencies.

In order to provide a lighter-weight and lower-cost unit which retains most of the good features of the two-way loudspeaker, the design now known as the dia-cone was developed. The name dia-cone is derived from "diaphragm" and "cone" and applies to a loudspeaker having both a high-frequency diaphragm and a low-frequency

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* Presented Apr. 22, 1947, at the SMPE Convention in Chicago.

** Altec Lansing Corporation, Hollywood, Calif.

cone driven through a mechanical network by a single large voice coil. The combination thus gives many of the advantages of a true two-way loudspeaker without the accompanying high costs of double magnets, double voice coils, crossover networks, and the additional costs necessitated by a complicated mechanical construction.

FIG. 1. Side view of Model *603* multicell dia-cone loudspeaker.

The Model *603* multicell dia-cone loudspeaker (Fig. 1) employs a 3-inch voice coil having an inner diaphragm made of dural, and an outer cone which is made of seamless molded felted paper. At frequencies above 2000 cycles the mass of the outside cone is very large and, as a consequence, its ability to radiate sound uniformly decreases as the frequency increases. Attached to the voice coil directly is a domed metal diaphragm 3 inches in diameter. This metal diaphragm has a high stiffness-mass ratio and high sound-transmission speed. It is able to operate as a piston even though the outside cone fails to provide the proper movement. The voice coil and inner diaphragm vibrate independently of the outer diaphragm at the higher frequencies because of the compliance in the cone immediately outside the area and adjacent to the voice coil. The vibrating area of the metal dome is small in comparison with the wavelengths of the frequencies being radiated, and for this reason the angle of distribution is considerably widened over the single cone. The amplitude of the high-frequency diaphragm for uniform radiation of acoustic power decreases with an increase of frequency.

For this reason, considerable acoustic power can be radiated at the higher frequencies from the 3-inch diaphragm with a comparatively small excursion. At low frequencies, this center portion vibrates in

phase with the outer diaphragm and provides the maximum possible vibrating area. In order to enhance further the distribution pattern over the high-frequency range, a cast-bakelite 6-cell horn is mounted directly in front of the metal dome, as shown in Fig. 2. A clearance of about 150 mils is provided so that at its maximum rated power there is no danger of the metal dome's striking the throat of the horn. The multicellular horn is held in position by means of two studs which

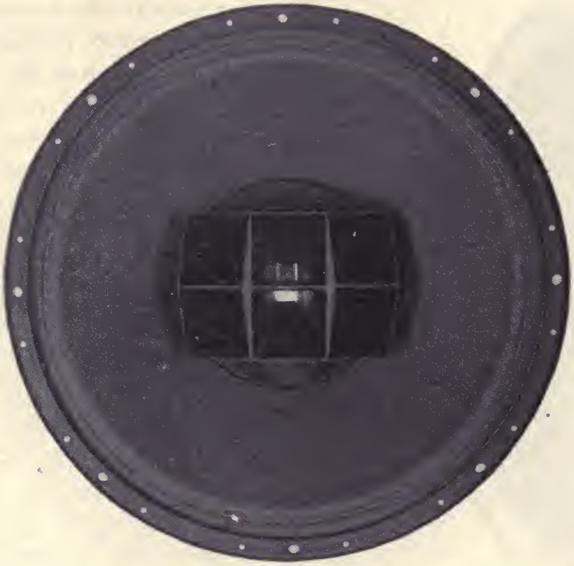

FIG. 2. Front view of Model *603* multicell dia-cone loudspeaker.

are threaded into the top plate surrounding the voice coil and pole-piece structure. Clearance holes are provided in the cone for these studs. Acoustic-performance tests indicate that the multicellular horn greatly improves the radiation pattern of the loudspeaker and provides sufficient loading to reduce the irregularities in response.

An edgewise-wound aluminum-ribbon voice coil is used. The use of edgewise-wound ribbon improves the space factor over that of round wire, and since more conductor material can be placed in the air gap, the efficiency is raised and the operating temperature, with higher power, correspondingly decreased. Since the 3-inch voice-coil diameter is considerably larger than the voice coil normally used on

loudspeakers intended for this service, it has correspondingly increased ability to handle higher power without undue temperature rise, and as a result, the efficiency is little affected by changes in power.

The outer rim of the cone is cemented to the frame. The central spider assembly is attached to the cone outside of the voice coil and is of the accordion type, so as to permit large low-frequency excursions with low distortion. The resonance of the cone and voice-coil assembly is approximately 55 cycles in free air.

FIG. 3. Side view of Model *600* dia-cone loudspeaker.

An Alnico V permanent magnet is provided for the field excitation, and the total energy available with this magnet is greater than that previously supplied in the field-coil-type loudspeakers. The magnet itself is of the center-core type. The soft magnetic material, forming the path between the pole pieces, is amply designed so that the flux is conducted through the outside walls and up to the air gap where the voice coil is mounted, with little loss. The external leakage loss is extremely low. Additional benefits from these features of the design are increased efficiencies owing to lower magnetic losses, and the fact that it is possible to handle this unit without endangering wrist watches or other devices which may be susceptible to damage from magnetic fields.

The Model *600* dia-cone loudspeaker is similar to the Model *603* just described. (See Fig. 3.) It is mounted on a 12-inch frame, and the vibrating system has an area of 67 square inches as compared to the 123 square inches for the *603* unit. In order to reduce the weight and cost for portable application, the multicellular horn is not used. (See Fig. 4.)

This represents some compromise in response and distribution compared to the *603* unit. Both the *603* and *600* speakers have an impedance of approximately 10 ohms at 1000 cycles, and their efficiency is such that they will deliver 89 decibels (reference 0.0002 dyne per square centimeter) on its normal axis at 5 feet with an input of 0.1 watt.

The Model *604* duplex loudspeaker has been described in a previous meeting of the Society. Briefly, it is a two-way speaker using individual diaphragms, voice coils, and magnets for each unit. An electrical dividing network is used and the frequency crossover is approximately 2000 cycles.

FIG. 4. Front view of Model *600* dia-cone loudspeaker.

This loudspeaker is 3 decibels more efficient than either the *600* or *603* speakers in the range from 100 to 2000 cycles, and considerably more efficient beyond this range. (See Fig. 5.) It is being used in fixed and semiportable installations where the highest quality is desired. Club cars and dining cars on railroad systems are using this loudspeaker in connection with their 16-mm-film entertainment equipment. Other applications include schools, clubs, and private homes.

When using *600* and *603* loudspeakers with amplifiers having negative feedback which includes the output stage, the maximum true bass response can be obtained when the internal output impedance of the amplifier is approximately 10 ohms. It is not alone sufficient that the amplifier be rated for a 10-ohm load, since the use of very large amounts of feedback may produce output impedances very much lower than the rated impedance of the amplifier.

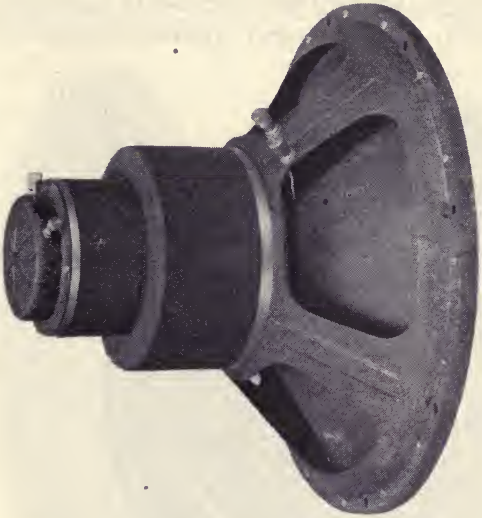

FIG. 5. Side view of Model *604* duplex loudspeaker.

An amplifier-output impedance, several times lower than the speaker impedance, should be used only in connection with loudspeaker cabinets which are of improper design, producing boominess.

Cabinets of the turned-port type are recommended where the maximum bass response is required consistent with limited space.

The frequencies indicated on Fig. 6 are recommended points of resonance for the indicated volume of the cabinet.

If, for any reason, it is desirable to change the frequency of resonance of the port, the following procedure can be used:

1. Select the frequency where the port is to resonate or provide maximum response.

2. By means of an audio oscillator and amplifier of correct output impedance, provide approximately 1 watt at the voice-coil terminals at the selected frequency.

3. Place a volume indicator, vacuum-tube voltmeter, or other measuring device across the terminal of the loudspeaker.

4. Adjust the area of the port until a minimum deflection is obtained on the meter. This area then provides the maximum acoustic response possible for the selected size at the measured frequency.

It is desirable to mount the speaker as high in the cabinet as

possible. This height is necessary so that the direct radiation from the loudspeaker will not be obstructed by furniture, and so that reflections from the floor will be minimized.

Fig. 7 shows the *612* utility cabinet which has a volume of approximately 6 cubic feet, and the port is tuned to 60 cycles. It is also lined with fiber-glass panels.

Fig. 8 shows the *614* portable cabinet which has 3.2 cubic feet, and is resonated for maximum response down to 85 cycles. This cabinet is intended for portable public-address and 16-mm service.

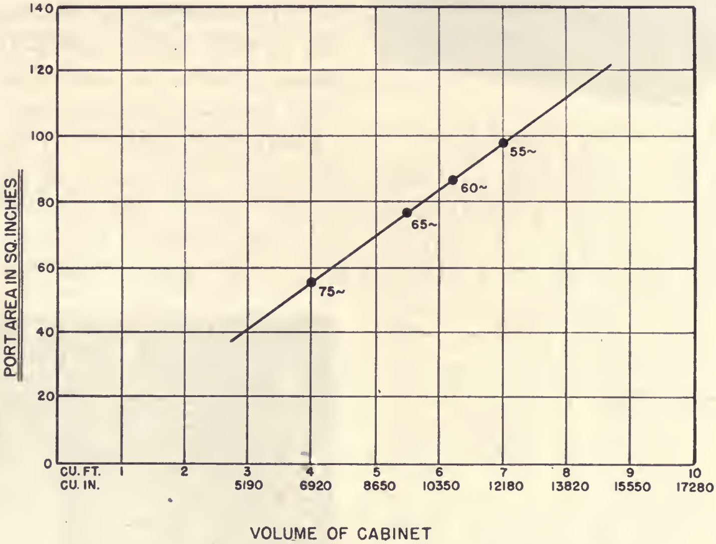

FIG. 6. Chart showing area of port versus cabinet volume.

In order to demonstrate these loudspeakers, especially prepared 16-mm prints were made and reproduced on a projector which had been designed around the Joint Army and Navy Specifications, prepared by the *ASA-Z52* War Photography Group. The over-all response of the entire system, as measured with the *Z22.44-1946* 16-mm test film, is uniform within 1 decibel in the low-frequency region down to 60 cycles. In the high-frequency region, the response was uniform up to 4000 cycles and −2 at 5000 cycles and −8 at 7000 cycles. The total flutter, when measured according to the latest standards of rating flutter, is not greater than ±0.1 per cent. Additional information on the frequency test film used and flutter measurement

FIG. 7. *612* utility cabinet.

standards can be obtained from the office of the Society of Motion Picture Engineers.

One sample of film demonstrating solo voice and piano was originally recorded on 200-mil push-pull variable density, and then re-recorded to a 16-mm negative from which the final print was made. The response of the re-recording system was set so as to be approximately the same as that of 35-mm technique. The second selection was a 20-minute short subject. This film was re-recorded from a 35-mm variable-area track on to a 16-mm negative. Some manual compression was used to reduce the volume range at the time of re-recording. The processing on the print was adjusted so as to give a minimum of −30 decibels cross modulation.

The demonstration was given in the Esquire Theatre, which has a seating capacity of approximately 1500. The amplifier system used had an installed capacity of 20 watts. The efficiency of the loudspeaker is such that approximately 5 watts of electrical power were required to produce the required acoustic energy considered adequate on the basis of 35-mm presentation of musicals. The demonstration used a Model *603* loudspeaker mounted in a *614* cabinet, having an enclosure of approximately 3.2 cubic feet.

FIG. 8. *614* portable cabinet.

The results of this demonstration indicate that when all of the elements of the system such as recording equipment, projector, and loudspeaker meet certain minimum standards, 16-mm quality can be competitive with 35-mm sound systems.

A SURVEY, 8-MM PROBLEMS*

ROBERT E. LEWIS**

Summary.—*Source, size, lens aperture, steadiness, film resolution, and similar factors govern the present-day and anticipated future limits of 8-mm motion pictures as to dynamic resolution, illumination, and possible sound on film.*

In order to evaluate the subject to screen performance of motion picture systems, a test method was employed which indicated the total resolution of the camera, film, and projector. In order to record resolutions equivalent to those seen by eye, it was found necessary to add the images of several frames because of persistence of vision. The same conditions appear to apply to television.

I. INTRODUCTION

In the absence of basic papers dealing with the problems of 8-mm equipment and performance, there appears to be a need for the reexamination of the basic precepts in view of recent developments and trends. One of the peculiarities of the field seems to be the apparent disregard for the need of engineering knowledge in a class of equipment operating at magnifications equivalent to most optical microscopes. The probable reason for the lack of engineering study of 8-mm equipment is the apparently prevalent concept that such equipment is largely a problem requiring only mechanical engineering to the exclusion of the optical and electronic knowledge. An integration of all three is required as in motion picture engineering practice with other size films.

A crude survey of equipment costs shows that there is little difference in the cost of 8-mm apparatus as compared to 16-mm apparatus of similar manufacturing quality; in fact, in some instances the mechanisms are somewhat interchangeable. The fundamental design character then rests largely with the film size itself. The economy is due to more than a small image, because of the use of 16-mm processing equipment, handling 8 mm as dual 8 mm prior to splitting. It is possible to conceive a considerable number of arguments for films of other dimensions which will allow greater economy by more efficient use of the emulsion area, such as 9.5 mm which allows a frame image very nearly as large as 16 mm, or a possible 4-mm size which by the saving of area by the use of a notch-and-ratchet pull-down may

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Armour Research Foundation of Illinois Institute of Technology, Chicago 16, Ill.

have a frame size the same as 8 mm. However, the fact remains that, unless considerable economy over the present 8-mm size is possible, the quantity of production will not be sufficient to guarantee low camera and projector sales prices. If, on the other hand, the addition of sound to 8 mm is contemplated, the reduction of the presently unused emulsion area must be considered differently. It is obvious that 8-mm film was conceived for silent-picture use, or the frame would have been rotated 90 degrees to allow faster film velocity for the same picture-area utilization.

The fundamental characteristic of 8-mm film is then largely due to the use of a small frame which allows economy of film, though at the same time using available 16-mm processing stations. As the frame size is close to one fourth that of 16-mm film, one would expect a screen sharpness one quarter that of 16 mm with other factors the same. From the strictly interpreted viewpoint, the comparison of subject to screen performance resolution is the final criterion. There is, however, another possibility which permits a definitely different viewpoint; namely, whether the system will produce a satisfactorily sharp image over a screen of 8 by 10 inches, for example. When considered from the standpoint of a screen of limited dimension, resolution above the acceptable point becomes superfluous. If resolution equivalent to newspaper quality is considered acceptable, then approximately 500 horizontal lines are required. The design of a projector under such considerations then becomes a cross between an editor and a "juke box", similar to a desk-model television receiver. That 8 mm is to television what the phonograph is to amplitude-modulation radio seems logical.

In view of the above discussion, the following is a survey of the factors which influence the performance of 8-mm equipment, in terms of design quantities and fundamental equations.

II. FILM

Film for 8-mm cameras may be purchased in three types of loadings: single-eight, double-eight, and double-eight magazine. Eight-millimeter projectors use single-width 8-mm film universally, with loading being by means of manual threading from standard reels. Neither magazine loading nor automatic threading for 8-mm projectors has appeared on the market as yet.

Though one 8-mm frame requires one quarter the area of a 16-mm frame, the current cost per foot of 8-mm film is not of that ratio, but

on the projection time basis more nearly two to one. Thus on the number of lines resolved per dollar basis, the 8-mm user now gets a value of about one half that of the 16-mm user.

From the standpoint of comparative performance, an 8-mm image cannot win, yet for an acceptable image for home use, the frame is apparently adequate. If a film resolves 60 lines per millimeter, 180 lines per frame will be resolved for television scanning or 240 when scanned the other way at right angles. Microfilm emulsions resolve 120 lines per millimeter giving 360 by 480 lines per image. Emulsions resolving as high as 500 lines per millimeter have been made for spectroscopic plates (Eastman Kodak Company, Type 548), which if coated on 8-mm stock would give 1500 by 2000 line images. The use of an emulsion as slow as the last would not be practical for camera, though by reduction printing from 35 mm, full realization of its potential could be had.

If the perception of movement on the screen by the eye is assumed to be at a limit at 16 frames per second, and the perception of flicker or intensity modulation disappears at three times that, or 48 cycles per second, we have a basis for further investigations of image conditions. If these conditions are properly met, we will then have three interruptions per frame at silent speed so that in two sixteenths of a second, two frames appeared three times each for a total of six. Also, if we choose at random an interval of one sixteenth of a second, we may have an interval containing one showing of the first frame and two of the second and so on. Consequently, the eye actually sees a mixture of two or more frames. If two frames are seen, it is improbable that persistence of vision would cause an improvement in resolution equal to more than the number of frames taken as a factor; in this case, twice. For 60-line-per-millimeter film, this resolution would result in a picture of 360 by 480 lines and so on. For the same film at sound speed, three frames may be seen enough to be visually integrated to resolve not more than a 540 by 720 line image. At television speed, 30 frames per second, a picture of fully twice and probably nearer three times resolution is possible as a limit. Needless to say, if the mechanism does not place each frame in exactly the same place, image deterioration will result, which result is due also to persistence of vision.

From the theory of persistence of vision with regard to resolution, we see that a finer line may be shown from the same emulsion when used as a motion picture rather than a still picture, assuming all other

factors the same. Therefore, inasmuch as single frames of 8-mm film will appear when seen as stills, half as sharp as the motion picture, there will in all probability be little demand for stop-on-film constructions popular for 9.5-mm film in Europe.

TABLE 1

MAXIMUM PROBABLE RESOLUTION DERIVED FROM PERSISTENCE OF VISION EFFECTS AT 24–30 FRAMES PER SECOND

Film, Lines per Millimeter	Horizontal Lines per Image	Vertical Lines per Image
60	540	720
120	1080	1440
500	4500	6000

III. OPTICS

As films resolving 60 lines per millimeter are commonly in use today, the persistence of vision effect alone would seem to indicate that lenses resolving at least 120 to 180 lines per millimeter are required for full use of the resolution potential by both the camera and the pro jector.

For microscope use, lenses resolving 300 lines per millimeter over the entire frame are currently available with exposure-control diaphragms. The similarity between 8-mm lens and the microscope objective does not end here, for the element sizes, centering problems, and similar problems are very nearly the same. However, the 8-mm lens at present is unnecessarily restricted as to back clearance and outside diameter. As the fields are nearly the same and the magnifications required of the same order, it appears logical that the numerical aperture of the objective will determine its resolving power when abberrations are corrected. Therefore, the faster the lens, or the larger the numerical aperture, the higher the resolving power. It seems in order at this point to predict that the present commercial limit of relative aperture ($f/1.4$) will soon be opened up in favor of sharper pictures as well as more favorable exposures.

This will not be possible if the present back clearances must remain so great that the microscope design types of lenses are ruled out. Lift-out turrets and back-opening gates offer an obvious answer. Likewise, high relative aperture designs and wide-angle designs are very often made useless by the poor mechanical clearances allowed for the lens mounts. All too often the lenses of a turret are so close

together that one shows the other in the picture, if the other can be mounted at all. The economies of small gears often cause projector designers to place the sprockets so close together that the outside diameter of the lens is restricted to the diameter of the particular Petzval objective the designer intended using. This often makes the use of an anastigmat or other type of objective impossible. This type of error is all too characteristic of the mind that knows nothing outside of mechanical engineering and, therefore, never does a complete job of motion picture engineering.

Eight-millimeter cameras are particularly fortunate in one respect; because of the small picture size, the focal lengths of the lenses are short and thereby a great depth of focus is acquired. This enables practical use of relative apertures impossible in longer focal lengths. There is another side to the same story, however; a great shift in the object distance results in a small shift in the image distance; a small shift of the same order of the lens away from the film results in a great shift of the median focus in object space. As a result of this effect, 8-mm cameras are on the market which, according to the combination of magazines, lenses, turret, or whatever else is involved, the "infinity" focus may be anywhere from 6 feet to beyond infinity (if such a term exists).

Others have demonstrated quite adequately that with known tungsten sources little improvement can be expected of present-day illumination systems for projectors, because of the restricting effects of filament size, bulb diameter, frame size, and lens aperture. In short, only by the use of objectives of higher relative aperture and condensers to match, can more lumens be supplied to the screen from tungsten lamps.

Arc sources as yet have not been demonstrated to be commercially attractive in the 8-mm field. On the basis of area of the aperture, using a 16-mm arc delivering 1000 lumens to the screen, it is probable that at least 250 lumens would reach the screen for 8-mm use. The zirconium concentrated arc shows promise but no data are as yet published concerning the lumen output for 8-mm projection with it. Until better screen illumination is possible, it is therefore again necessary to point out that 8-mm screen images are best kept small.

In the struggle to extract all of the lumens possible out of the projector, design of the shutter is often special in an effort to take advantage of the flicker frequency or other characteristics. The usual result of such special designs, which depend on interrupter blades

smaller than the pull-down blade, is to produce flicker by visual discrimination between long and short interruptions. It is common in projectors to use pull-down times equal to two-skip or more movements in order to obtain greater light transmission without travel ghost. The same skip design as yet is not used in cameras wherein the pull-down usually occupies nearly 50 per cent of the cycle ($^1/_{30}$ of a second for silent speed), where an exposure of $^1/_{20}$ second or longer is possible.

It is all too recurrent a practice that the lamphouse of a projector is so designed that the operator may blind himself by looking at a brightness of 1000 foot-lamberts or more so that the image on the screen is no longer visible to him. If he is fortunate enough to escape being blinded from this, the gate usually causes an after image in the same manner so that focusing is still difficult. No brightness above the screen level should be visible at the projector position.

Because of the optical leverage of such a short focal length as required for 8-mm use, the misalignment of an objective and finder in a camera may easily result in an error of pointing in excess of the usually permissible 5 per cent. The widely used negative finder (reverse Galilean) allows eye parallax also, not to mention the effects of the diffused edge of the mask. Therefore, it is better not to use this finder on some cameras. The so-called positive or erecting telescope type of finder and the single-lens reflex type such as the Cine-Flex or Arriflex offer a solution in principle, but as yet, not at low cost. After the turret has been rotated, an error of positioning will also destroy the accuracy of a finder, especially if the lens seats are not indexed identically for each lens.

The use of optical rectification to substitute for a mechanical intermittent has many advantages, and a few systems[1] have been devised which produce reasonably good pictures. However, to date these systems suffer from a poor illumination output because of the restricted relative aperture and long focal length required of the lenses.

IV. STRUCTURE

Perhaps the most advanced and finished work of 8-mm equipment may be said to be at present on the mechanical structure of 8-mm cameras and projectors; yet some contemporary engineering shows a peculiar disregard for the basic requirements; for example, the careful finishing of a gear while at the same time misaligning a lens. The

basic concept behind such construction is no doubt related to the consumer attitude as conceived by the designing group.

That the consumer will ultimately choose the equipment giving better performance whether it be judged on the basis of cost, quality, or convenience cannot be denied without denying the worth of much in the way of engineering. On such a basis, it is difficult to see precisely how an image either out of focus or improperly pointed can be compensated for by an unseen gear built for a hundred years' life.

The number of lines-per-millimeter resolution required of present-day equipment is virtually a definition of the requirements of lens mounting as it concerns camera and projector construction. An interpretation of the optical requirements of an 8-mm piece of equipment must be viewed with the thought that it is in reality a projection microscope with an intermittent movement working almost as a micromanipulator, except at high speed. The projection of each error may be said to be roughly doubled, if the same error is made in both the camera and projector, and even tripled if a printing is involved. The skewing of a lens axis with regard to the correct axis determined by the frame center, the mispointing of a lens, or incorrect alignment of finder and camera axes may all cause unsatisfactory images whether soft or sharp but with cutoff heads of subjects, or both.

If the camera has one interchangeable lens, or a turret of several, the lens-mount problem exists much more than with a single fixed lens. It seems like a platitude to say that with interchangeable lenses the cameras and lenses must have threads, clearances, and faces to match. At present, no standard for 8-mm camera lens mounts exists comparable to the *C* mount for 16-mm cameras. Between the different lens positions of the turret of some makes of cameras one lens will focus from 6 to 8 feet to nearly infinity when left at a 12-foot setting. This naturally causes disfavor for high relative aperture lenses and complicates their purchase. Likewise, in the design of a turret, the mechanical conditions may, in another way, limit the performance more subtly by restricting the lens designer as to the back clearance permissible. If such a problem is posed, the only alternative is the use of inverted telephoto types with the added expense of adding and subtracting power. Better than a dodge is the use of a turret design that allows a maximum of back clearance in depth and diameter. The use of a reflex shutter for single-lens nonparallax focus while photographing limits the back clearance, but for a good reason at least.

A projector faces much the same type of problem. Without a

large-diameter lens barrel and adequate back clearance, either wide-angle or high-aperture lenses will be restricted if not ruled out. This requires a considerable dislocation of mechanism designs. In many cases, as the increase of barrel diameter separates the sprockets, and likewise causes the location of the pull-down system to be further removed from the optical axis, there is thrown in more of the effects of film shrinkage and the like to add to the problem of unsteadiness. If the intermittent is placed on the side away from the lens, the gate will best open toward the lens which makes it more difficult to remove and replace a field-flattener lens or any other optical system near the film.

The gate assembly of a projector must also contend with splices, some of which will be very bulky and throw the picture out of focus visibly when passing. This may be minimized with articulated springing so that the splice does not jar the gate open in one frame to remain so until the splice passes completely through. An apparently classical debate seems to exist in engineering circles concerning the use of side tension to position the film in the gate. The head or basic mechanism of the projector is then a single unit of design, wherein the image requirements set the lens design, which design in turn usually determines the illumination-system character. This combination of optical systems sets the clearances and diameters to be considered, thereby setting the minimum sprocket spacings, how the gate will be opened for threading, the location of the intermittent (or the optical axis to intermittent separation by frames), and also the shape and position limits of the shutter. In short, the head is fitted to the optics to obtain the best performance.

The problem is virtually the same for a camera, with, for example, the substitution of a magazine in the place of the condensers.

In essence, the determination of the resolution and illumination desired as an end product define conditions of performance which virtually decide the design conditions of the structure. The desirability of a synthesis of design quantities need not be pointed out as opposed to the empirical and, therefore, ultimately wasteful system of designing portions of the head independently to be fitted into a final assembly. Because of the more widespread knowledge of mechanical rather than optical problems, the usual result of the latter method is the incorporation of identical and limited lens systems in design after design so that, if the mechanical structure were improved, it would not show very well.

The point of translation between optical requirements and the

performance of the pull-down system is the definition of dynamic resolution; namely, the exact nature of the equation connecting the resolution of a single still image and the projection of a succession as in a motion picture as seen by the eye. When this relationship is clearly defined, the tolerances of the entire system may be defined and tolerances balanced for manufacturing use. The factor between still and dynamic quantities is also determined by the film-perforation accuracy as well as persistence of vision.

With the film held to a tolerance of ± 0.0005 inch (± 0.013 mm) between successive perforations, the low limit of resolution between successive frames, superimposed by persistent retinal images is roughly the reciprocal of the tolerance ($^1/_{0.013} = 77$), or 77 lines per millimeter. If the total of the tolerance is considered, however, the low limit sinks to 38 lines per millimeter. If the sidesway is controlled by the perforation, 100 to 50 lines per millimeter may be expected as a low limit. The width of the film, if allowed to control sidesway, will yield but 12 lines per millimeter, as opposed to guiding by the perforation side only, which gives about at the least 10 lines per millimeter, corresponding to the same tolerances for the aperture center line.

Considering the tolerances assigned to 8-mm film, the stacking of components enables the following estimation of the errors between successive frames as shown in Table 2.

TABLE 2

SINGLE-TOOTH STACKED TOLERANCES (LINES PER MILLIMETER)

	Lowest Permissible	One-Sided Error Only
Horizontal line resolution	21	43
Vertical line resolution	10	20

That such low limits are rarely reached is a matter of experience and empirical trial. It seems highly improbable that the vertical lines will be so poorly resolved, as the gate is normally several frames long such that the worst error drops easily to one fourth.

If several teeth are brought to bear on the film, the errors begin to reduce within the limits permitted of shrinkages such that between successive frames the stacked tolerance may be reduced considerably, depending somewhat on the pull-down teeth shapes and spaces. If the film shrinkage is within the usual limits and uniformly the same in amount throughout the entire length of the film, no effect should be readily discernible; if, however, a 2 per cent differential exists between

frames, a low of 13-line-per-millimeter resolution may occur. Such a shrinkage seems very improbable.

If the conditions are such that film perforations permit resolution equivalent to the optical system, the remaining link is the film-handling system. If the film-advance system is of a single-cycle type, has no nonrepetitive errors between frames, and if the film is not moved during projection, the picture should be asbolutely steady. However, inasmuch as many intermittents are mechanically magnifying the cam as translated into film motion, a variation between frames or cycles of lubricant film thickness of one half a thousandth of an inch will most likely result in a resolution drop to about 20 lines per millimeter. Under such conditions a reduction of leverage would appear advisable. At such tolerances, the use of a sprocket intermittent of six or eight teeth appears impracticable because of the probable six- to eightfold magnification of manufacturing errors in addition to those just cited. The optical intermittent of the compensating and continuous moving-film type is unlikely to have a very good opportunity to compete in so far as resolution is concerned, as it must be driven by a sprocket or similar construction.

As the resolution of an 8-mm piece of equipment is definitely a quantity related to its design, the designation of the means of measure of such is of value. The resolution of the objective may well be handled by tests similar to the standard 16-mm projection-lens test. The film constitutes no problem. The dynamic resolution, on the other hand, constitutes a problem depending upon the conception of persistence of vision. If the eye were a device opening and closing its sensitivity rapidly, the problem would be simple, but the smooth and individually variable slopes of the curve introduce enough variables to confuse the issue. It is suggested that the dynamic resolution be tested by normal motion picture projection through a shutter for an exposure of between $^1/_{10}$ to $^1/_{16}$ of a second, using a film as screen to integrate the image during exposure. A test of this type integrates the total performance of the system from subject through camera and projector but not including the screen. Utilizing this approach, Table 3 was obtained from equipment chosen at random.

Photography of the screen image completes the resolution chain but adds an unnecessary factor.

The camera film-handling system must be driven at such a speed that the exposure does not change visibly during a scene. Also, a camera must start and stop within a frame, always dark in the dead

position. The mechanism other than the governor and intermittent may therefore be crude but not so crude that it is noisy and causes distraction of the subjects. The speed regulation may be due to a governor exerting a drag. Escapement regulation similar to a watch has not as yet appeared in cameras, though various electric controls are being used for cameras and projectors.

TABLE 3

INTEGRATED DYNAMIC RESOLUTION (BLACK AND WHITE)

$^1/_{10}$ second	80 (a few lines of 112 L/mm show occasionally, Fig. 1)
$^1/_2$ second	40 (grain pattern gone entirely, Fig. 2)
Visual	80

Among various factors causing image deterioration, the rigidity of support of the camera itself is a factor in so far as the consumer is concerned. A loose tripod thread and a small base on the camera are not good aids to secure mounting. The hand-held use of pocket-type cameras is also a very important item in this regard. An angular movement of $^1/_{100}$ radian may cause a degeneration of resolution down to 8 lines per millimeter, if it occurs in a period equal to one frame.

Numerous aspects enter into such a picture, including the type of sight, the trigger-release pressure, and its position, not to mention the possible friction of the trigger end. The type of case construction enters into the picture from the same tactile sense. A further factor, usually ignored, is the moment of inertia of the moving parts. The jerk on starting or stopping can well cause such a loss in sharpness.

V. SOUND

That sound with 8-mm film is desirable cannot be denied; the problem is more likely, what is acceptable? The use of disks or magnetic records synchronized with the films is capable of very fine performance except for the already well-known troubles of film repair and synchronization. Sound on film for 8-mm use at present is still a matter for laboratory discussion.

Optical tracks may on the basis of current practice reach as high as 3500 cycles if 7000 is accepted as the top for 16 mm. With high-resolution stock (microfilm) and precisely controlled conditions, frequencies as high as 5000 cycles can be prophesied so far as the laboratory is concerned. Yet, the problems of 8-mm sound on film hinge on other factors, yielding to indirect attack only. The noise level in 8-mm optical sound is so high that, if good frequency response is

attained, it must again be thrown away by the use of cutoff filters. Volume expansion by means of a separate control track has been suggested. The amount of space available for the sound track or tracks is not very adequate, as the picture area must be robbed or the track

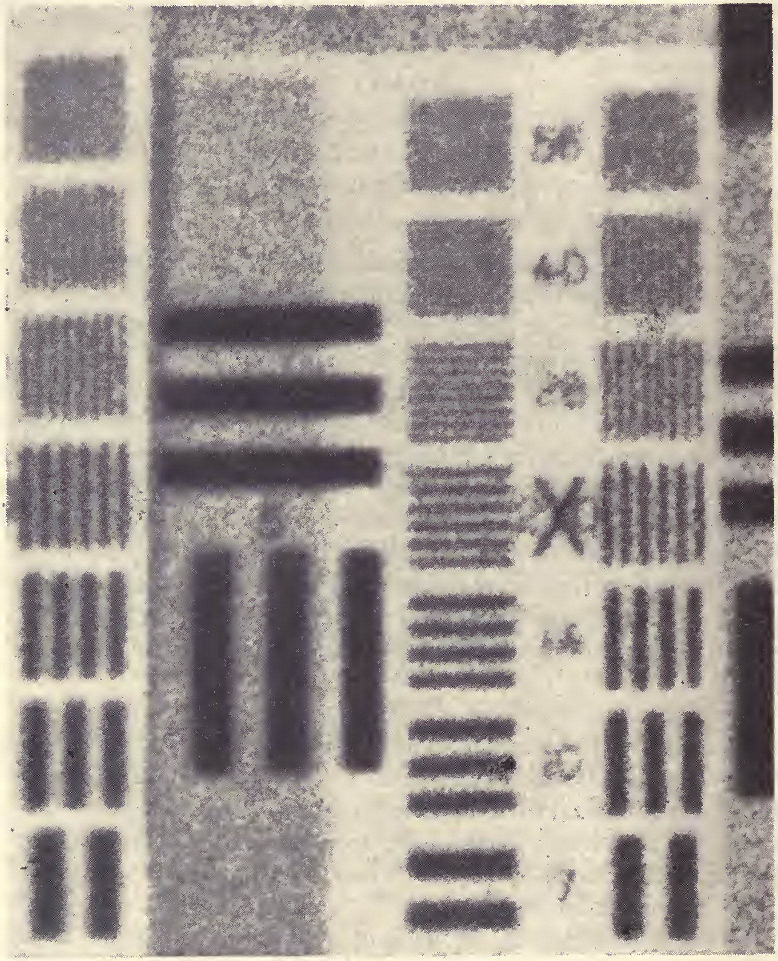

FIG. 1. National Bureau of Standards charts were photographed by an 8-mm camera, and the film processed and projected upon photosensitive material for a screen. Exposure is made by a shutter in front of the projector. These charts were at twice the usual distance such that the line-per-millimeter resolution must be doubled. (Top line, 112 lines per millimeter.) Extreme care is required in taking such pictures to attain the maximum resolution as it fluctuates rapidly.

placed outside the sprocket holes. This places the sound track in a location where developer activity is very likely to produce flutter, unless a viscous developer is applied by rollers or the like to avoid the effects of the adjacent sprocket hole. The very slow speed of 8-mm film even at 24 or 30 frames is such that the construction of film-transport systems for sound reproduction becomes very difficult.

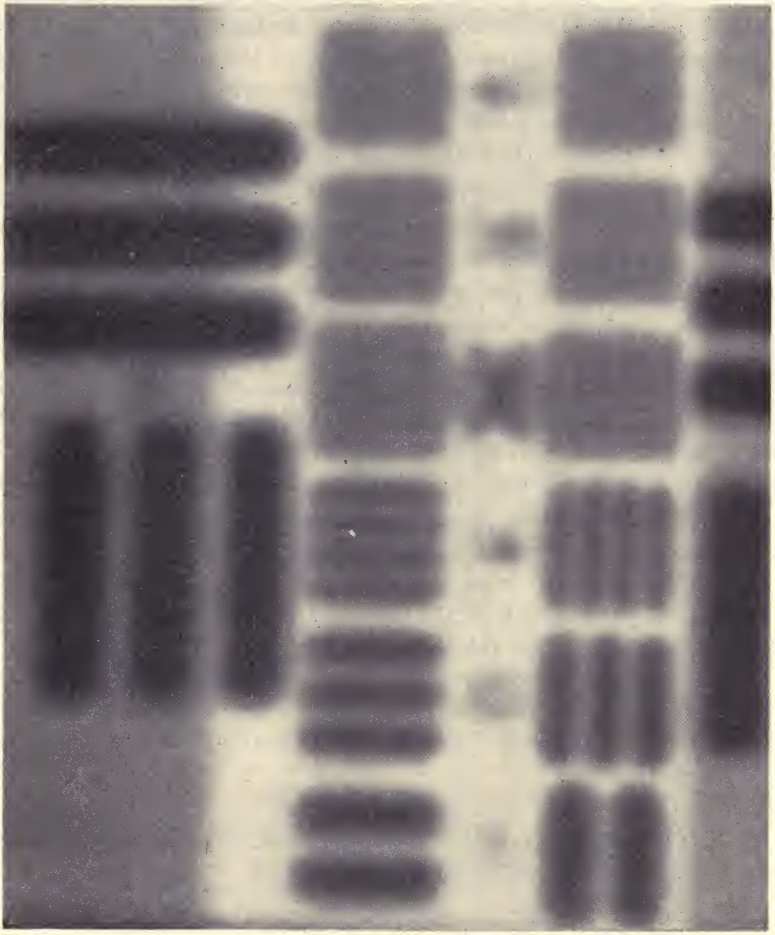

FIG. 2. A $^1/_2$-second exposure under the conditions of Fig. 1 produces a pattern wherein grain is no longer of consequence. If the motion picture equipment were perfect and the film perfectly perforated this exposure would probably exhibit higher resolution than Fig. 1.

The 8-mm sound-on-film scanning systems will require better optics than the 50-line-per-millimeter slits at present used for 16-mm sound on film and also a spacing of more frames between picture and sound. (Fifty-two frames would allow direct conversion of much 16-mm sound-on-film equipment.)

At first glance one would suspect that the frequency response predicted for 8-mm magnetic sound on film[2] was a very poor condition. However, the lack of difficulty with dynamic range and sprocket-hole modulation caused by developer products and a very favorable noise ratio show very great promise in addition to the advantage of being able to record at home without additional processing. The variation in flexing of the film at the sprocket holes is no more likely to be a problem for magnetic than for optical sound.

VI. CONCLUSION

With the advent of sound for 8 mm, and the construction of the projectors as a complete unit assembly including the screen, the installation of motion picture projectors, along with television sets, is likely to become a parallel in sales to the installation of phonographs with radios.

A complete study of the performance of 8-mm material in terms of resolution has not been published and is definitely needed to enable adjustment of design to avoid unnecessary losses. Among the various items needed are data on printing resolution, screen resolution, maintenance of the focal plane in operation, and more thorough data on dynamic resolution and persistence of vision effects.

There will probably arise a desire for the study of the numerical aperture of optical printers, the effects of diffraction in printing, and the possibility of higher-resolution color film.

In the process of realizing the above, it seems safe to prophesy that the future will see the increased use of basic-design quantities derived from laboratory research rather than the traditional and strictly drawing-board approach.

ACKNOWLEDGMENT

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DESIGN PROGRESS IN AN 8-MM PROJECTOR*

THOMAS J. MORGAN**

***Summary.**—This paper outlines the design objectives involved in the production of a precision-made 8-mm projector, consideration being given to sales attractiveness in styling, distinctiveness, and simplicity of appearance; problems in film handling, simplification of functions, minimizing operational controls, illumination efficiency as correlated with film movement and optics; temperature control, and production cost economy in parts and assemblies.*

Exhibiting equipment for 8-mm moving picture film became predominantly domestic because of its use being confined primarily to the individual or the amateur enthusiast.

Under these circumstances, it seemed imperative that a distinct departure be made from the orthodox style of projector design which is prevalent in 16-mm equipment. This probably was the first instance of a machine of this type being accepted as a definite part of the home living room.

It seemed evident therefore that the design of an 8-mm projector, in order to be acceptable in these surroundings, should embrace simplicity of design, attractive proportions, and distinctiveness of style; also it should be constructed so as to conceal moving mechanism as much as practicable and to minimize operational controls.

These were the design objectives outlined for the 8-mm projector, whose components and functions are to be described.

DRIVE MECHANISM

A universal motor was selected for this projector to provide either alternating- or direct-current operation, because of the economy in omission of the auxiliary equipment for operation and the preference for its high starting torque qualities. The projector load seemed sufficiently constant to overlook resultant speed changes and a rheostat control as provided, satisfactorily compensated for line-voltage and motor variations. Inherent noises in this type of motor are minimized by the control of the quality of the brushes and the commutator surface. The motor brushes are readily accessible for replacement.

The motor was so located as to provide adequate cooling by its

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** Ampro Corporation, Chicago, Ill.

shell exposure to open air and induced air currents through it leading directly toward the air intake of a housed fan mounted upon an extension of the motor shaft. The motor mounting is of the flange type and the motor is readily interchangeable in servicing without disturbing any of the mechanism.

The projector switch is the main control and the projection-lamp switch is fed through it, thus assuring lamp ventilation at all times except for possible motor failure or stalled mechanism. A motor-reversing switch is provided for either rewinding or reverse projection, and the plane of action of its handle is purposely positioned at right angles to the handle of the main switch for touch distinction in the dark. Reverse projection is obtained when the projector is running forward by merely throwing the motor switch to "reverse". These switches are closely and conveniently grouped in the base near the rheostat and the line receptacle for ease of operation, short leads, and connections.

An uncommon feature is the miniature threading lamp. It is provided without a control switch and so wired as to be "on" whenever the projection lamp is "off". A threading lamp effectively located, but also necessitating a series resistor, seemed preferable to an obviously cheaper installation of a larger 110-volt-type lamp ineffectively located elsewhere.

A simple economical and effective drive is provided from the motor to the main drive shaft by the use of a molded V belt and pulleys. This belt is also readily accessible for replacement if necessary.

The main drive shaft is provided with a simple friction disk clutch, both driving and driven members being zinc die castings. The driving member is designed to serve as a clutch member, a pulley, and a flywheel. Disengagement of this clutch stops all film transport mechanism for the express purpose of exhibiting still pictures.

This main shaft serves to drive two individual gear trains; one, the safety shutter and intermittent mechanism, and the other, the two 12-tooth film sprockets. Both upper and lower sprocket shafts in turn serve to drive both upper and lower reel spindles, respectively, by means of coiled spring wire belts.

The gearing is so arranged as to permit a higher velocity in rewinding, which is simply accomplished by threading the film directly from the take-up to the feed reel, by throwing the motor switch to "reverse" and the main switch to "on". The rewinding of 400 feet of film requires about $1^1/_2$ minutes.

INTERMITTENT

The shuttle is of the simple stamped lever type having its pivoted end so mounted upon a flat bronze spring as to permit of free vertical and horizontal oscillations alternately. This spring is anchored upon a bar having liberal vertical and minute lateral adjustments. On the opposite end of the shuttle is formed a single claw for film engagement.

The vertical adjustment provides film picture framing with a fixed aperture while the lateral adjustment permits claw-stroke regulation when the shuttle is maintained in working contact with its actuating

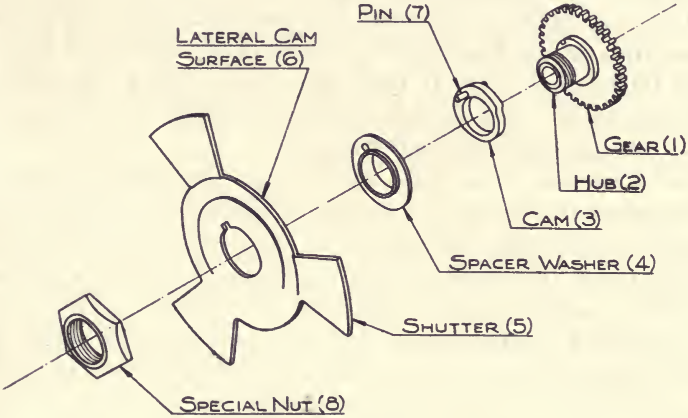

FIG. 1. Cam-unit assembly, exploded.

cam. This contact is made through means of a hardened and ground-steel follower button fastened to the shuttle. A similar button is used as the contact means between the shuttle and the vertical cam-follower spring. A Bakelite button on the shuttle is used as the lateral cam follower.

The cam-unit assembly (Fig. 1), mounted upon a stud, consists of a Bakelite gear (1); staked to an oilite bushed steel hub (2); mounting the vertical cam (3); a spacer washer (4); a three-bladed shutter (5); from which is extruded the lateral cam surface (6), which is circular in form and operates axially. This cam surface is oriented in timed relationship with the shutter travel blade. These three members are in turn keyed with a pin (7) in a predetermined time relationship and locked together with a special nut (8).

On the vertical cam the film-transport sector is represented by a curve subtending an arc of 24 degrees or the equivalent of a 14-to-1 movement. This enables one to use a shutter having three blades of only 35 degrees each and results in an extended light-exposure period amounting to 70.8 per cent of the picture cycle. This shutter is made of exceptionally heavy gauge steel in order to effect a flywheel function.

Adequate lubrication facilities, clearly indicated, are provided for all moving parts with particular consideration being given the intermittent unit.

REEL SPINDLES—TAKE-UP

Both feed and take-up spindles are driven by means of coiled spring wire belts and pulleys concealed from view within gracefully shaped die-cast arms designed as integral portions of the mechanism head and having removable covers at their rear thus allowing full access for belt replacement. The projector-carrying handle was also cast as a part of the upper arm for cost economy.

These arms were so designed and the spindles therein so spaced as to accommodate film reels of 400 feet capacity and thus provide a maximum continuous exhibition of 33 minutes at normal projection.

The take-up reel during forward projection having a gradually diminishing angular velocity clockwise, necessitates a device which will compensate for this change while driving the spindle. Except for the slight drag necessary to proper film-rewinding tension, this spindle must also be free to rotate in a counterclockwise direction during the rewinding operation.

Such a device was developed to perform these functions automatically and thus eliminate the necessity for any additional manual controls. Briefly, this device operates in reverse to the principle involved in a capstan where the amount of pull by the drum upon the fixed end of the medium is dependent upon the number of convolutions thereon and the degree of tension exerted at the free end of the medium. The reverse condition in this device is that neither the drum or spindle becomes the driven member through means of the medium, in this case a coiled spring attached at one end to a driven pulley and definite frictional drag applied at its free end. Under static conditions rotational impetus directly applied to the reel spindle in either direction has no influence whatever upon the winding or unwinding of the coiled spring which has relaxed normally and thus freed itself from the spindle.

All slippage accompanying velocity differentiation is absorbed within this device and therefore none is demanded of the driving belt or pulleys.

FILM GATE

The aperture plate is not provided with the customary film-guiding channel but has only a slightly depressed track for picture-protecting clearance. A plate of this type has less affinity for the accumulation of dust particles.

Three fixed film-edge guides on one side of the aperture are opposed by two film-edge-pressure springs on the other. Because of the edge curvature manifest in 8-mm film, the edge guides above and below the aperture are positioned at a greater distance laterally from the optical axis than the central guide directly opposite the aperture which accurately aligns the film with this axis. The edge-pressure springs are located symmetrically above and below the horizontal plane through the optical axis. The action of opening the film gate automatically retracts the edge-pressure springs for freedom in threading film between them and the edge guides.

The film gate is opened by means of a cam lever conveniently located upon a sliding lens holder in which is retained the film-pressure shoe. This shoe, although spring-floated and accurately retained in operating position, is free to be withdrawn easily for cleaning or replacement only when the gate is open. The stamped H spring urging this shoe is also readily removed for replacement without tools.

Shoe pressure on the film is controlled by an adjustable stop mounted upon the lens holder. Free access for properly cleaning the picture aperture is possible when the objective lens and the pressure shoe are removed.

OPTICS

The original design of this projector comprised a system having as its light source a 500-watt, T-10, 115-volt medium prefocused base lamp. Subsequently, however, the adaptation of a 750-watt, T-12 lamp and modified optics for same within the limits of the original lamphouse, included a 1-inch E.F., coated, $f/1.6$ objective lens, a single element, aspheric-convex condenser 22-mm outside diameter and a rhodium-surfaced reflector of 1 inch radius of curvature.

Illumination uniformity and output test results for this system using 750-watt lamps and a 16-mm standard test chart on a 40-inch screen were as follows:

The linear aperture magnification in the above tests for an 8-mm aperture of 0.172 × 0.129 inch is 232 to 1, while the linear aperture magnification in similar tests for a 16-mm aperture of 0.380 × 0.284 inch is only 105 to 1.

Objective lens focusing is accomplished in an orthodox manner of spring-ball engagement with the helical scoring provided on the lens barrel.

The projection-lamp socket is provided with a mounting unit having a simple adjustment screw for centering the lamp filament laterally. This screw may be adjusted externally of the lamphouse with a

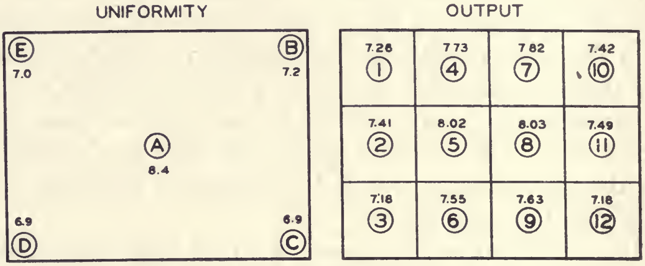

FIG. 2.

A

Averages of 6 lamps in foot-candles. Average drop-off at corners = 17 per cent.

B

Averages of 6 lamps in foot-candles. Total lumens output = 62.75.

TEMPERATURE CONTROL

coin or similar instrument. The condenser unit is accessible when the lamphouse cover has been removed and is easily withdrawn for cleaning or replacement of the element without tools. The reflector is adjustable along the optical axis only and may be removed easily for replacement.

Having the ventilating fan directly mounted on the motor shaft presented a very interesting problem in the design of the fan-housing scroll where the necessity for equal air delivery in either forward or reverse fan rotation was apparent. A unique solution of this problem thus resulted.

The usual procedure in designing the spiral-scroll curvature for a single-direction fan housing is a common problem. Our problem necessitated the development of both a right- and left-hand spiral scroll from a common cutoff.

These spiral curves (1), Figs. 3A and 3B, obviously intersect at a point (2), upon an extended line (3), drawn between the center (4) of the fan, and the common cutoff (5). This fact, therefore, definitely set the angular limit to which we could develop fixed-scroll curves moving inwardly or toward the center of development. It was obvious that the sectors necessary to the completion of each scroll between this point of intersection and the cutoff were similar. It eventually developed that one such sector alone would serve to complete

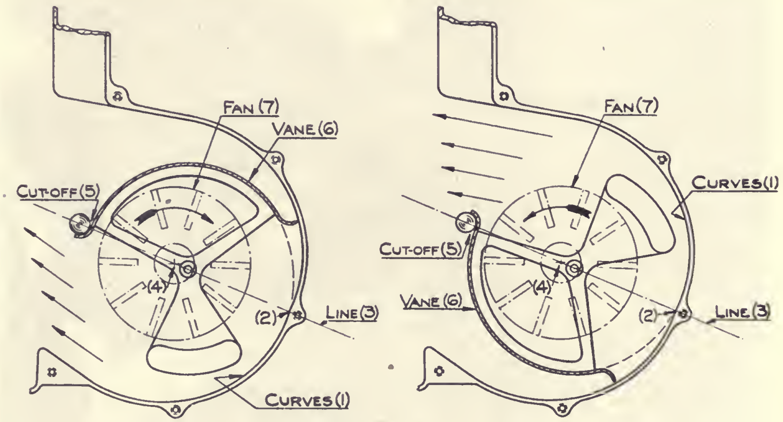

FIG. 3.

A
Vane position with fan rotating in forward position.

B
Vane position with fan rotating in reverse direction.

either scroll when constructed as a vane (6), whose contour approximated that of the normal sector and which was free to travel between the limits of these two positions. Either of these positions would be automatically determined by and dependent upon the directional impetus imparted to the vane by the air discharge from the fan (7) itself.

The limited angular spiral development under the above circumstances is recognized.

Anemometer tests for air-discharge volume and velocities, through a special stack, taken 12 inches above the top of the lamp for both forward and reverse fan directions and with the projector operating at 16 frames per second are shown in Table 1.

Table 1

Direction of Fan	Air Discharge Velocity Feet per Minute	Volume Cubic Feet
Forward	371.28	32.39
Reverse	383.80	33.49

Highly effective aperture cooling was accomplished by directing induced cool outside air currents across the back of the aperture

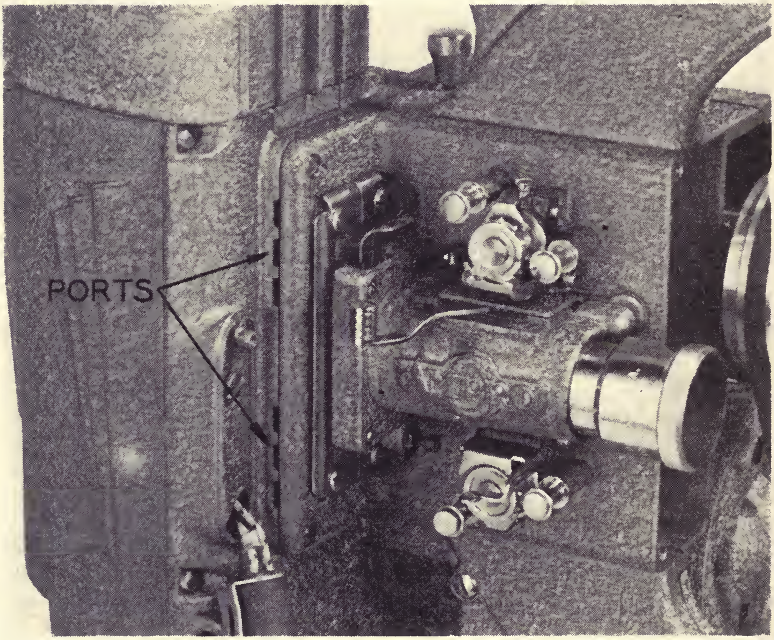

FIG. 4. Air intake ports for aperture cooling.

through ports indicated in Fig. 4, leading directly into a narrow heat-insulating chamber between the aperture and the lamp compartment and connected with the fan intake.

The lamphouse-cover unit includes lamp shielding providing double air-space insulation protection between lamp and external surfaces.

A grille as part of the lamphouse cover proper was designed to reduce ceiling illumination with a minimum impediment to discharging

air currents. Portions of the grille-design pattern projected onto the body of the lamphouse dually served in heat dissipation and in styling treatment.

Temperature tests for cooling efficiency at critical locations are shown in Table 2.

TABLE 2

Location of Thermocouple	Forward Degrees	Reverse Degrees
Aperture, $^7/_{16}$-inch radius from its center...	53.5	54
Lamphouse, left side*....................	83.0	84.5
Lamphouse, right side*..................	59.0	61.0
Lamphouse, rear*........................	61.0	64.0

* Thermocouples located external of lamphouse, in optical plane and directly opposite center of light source.

Temperature readings are centigrade scale.

Duration of "forward" tests were 45 minutes while "reverse" tests, which followed, were 15 minutes.

TILTING DEVICE

The tilt mechanism on this projector provides 15-degree upward and 5-degree downward adjustment of its optical axis. This is accomplished by the provision of substantial support in the main base of the projector for a sturdy pivot upon which the main projector head may rotate. A leg extension, forming a rigid part of the head, and channeled to conceal wiring passing around this pivot, projects down into the base chamber. The leg's lower extremity is provided with a slot designed to accept and fit a stud forming a rigid part of a special elongated die-cast nut. Because of its intimate contact with this leg, the nut is restrained from rotation. A shaft substantially journaled in the projection base and restrained from axial travel has a threaded portion projector within the base, designed to fit and support the nut.

Manual rotation of this shaft thus indirectly imparts a rotating or tilting movement to the projector head by the resultant axial movement of this special nut-stud component.

Obviously this device is self-locking and permits of accurate and effective adjustment. Care was exercised to locate the main pivot directly below the mid-point between the two extreme positions of the center of gravity of the projector mechanism. The net result of this effort was uniform ease of adjustment.

Manufacturing economy was realized in resorting to the use of die castings. Outside of a few critical parts, these castings required little more than simple drilling and tapping operations. An obvious advantage was the reproduction of neat, clean-cut, graceful shapes and forms, some much too intricate to contemplate otherwise, especially in view of the necessity for mass production.

Two typical examples of machining and die cost economies effected are cited here. First, rectangular openings in both the top and bottom of the mechanism head were required for the clearance of spring belts. These openings were inaccessible for direct machining. A slight change was made in the shape of a moving die core so the plane of its top surface would be coincident with the wall of the die cavity. This resulted in the simple coring of the desired opening which only necessitates removal of a slight flash in the raw casting. Second, very narrow gib slots in one casting were necessary for the guidance and retention of the condenser-lens-holder casting. This was quite impracticable to produce in the die with a sliding core because of its taper, depth, and narrowness. Straight coring from one side of this casting at the upper and lower extremities and similar straight coring from the opposite side of the casting in the center portion produced the desired effect of retaining gibs on both sides.

DIMENSIONS

The general over-all dimensions of the projector are $9^1/_4$ inches long $\times$ $6^{13}/_{16}$ inches wide $\times$ $13^7/_8$ inches high. The outside dimensions of the carrying case, exclusive of hardware projections, are 11 inches long $\times$ $8^3/_8$ inches wide $\times$ $14^7/_8$ inches high.

WEIGHTS

The net weight of the projector complete is 13.9 pounds. The gross weight of projector and carrying case including standard accessories is 22.2 pounds.

ACKNOWLEDGMENT

Grateful appreciation is hereby acknowledged for the helpful discussions with A. S. Dearborn and T. R. Neesley of this company upon the subject of this paper.

THE MOVIE-SOUND-8 PROJECTOR*

LLOYD THOMPSON**

Summary.—*The first commercial 8-mm sound projector has been introduced with the sound on a disk running at $33^1/_3$ revolutions per minute. An automatic-synchronization method is used, and the turntable and the projector are not mechanically connected. Eight-millimeter sound films for use with the machine are available.*

The first 8-mm commercial sound projector has been introduced to the market under the trade name of Movie-Sound 8. Sound on disk is the method used in obtaining the sound, and while sound on disk is certainly not new, there are two features used with the unit which we believe are new and which makes sound for 8 mm practicable.

The two things are, first, an automatic method of starting the film and disk in synchronism is used. This is done by recording on the disk, a one-thousand-cycle tone in synchronism with the synchronization mark on the picture. The projector is threaded with the synchronization mark in the gate. The pickup needle is set down on the revolving record. The one-thousand-cycle tone is picked up, and this operates a selective relay which starts the projector motor, and starts the two separate units in synchronism. It is true that a motor cannot start instantaneously but on a lightweight projector such as an 8- or 16-mm projector it will start almost instantaneously, but more important, the starting characteristic is quite uniform. Therefore it is possible to place the synchronization mark on the film so as to compensate for the loss in starting time. A special standardized leader has been made up and this leader is spliced on the beginning of any film which is to be printed and re-recorded for use on the Movie-Sound 8. This leader contains the 1000-cycle starting tone and the synchronization mark in their correct positions to make the sound and picture start in synchronism. The turntable and the projector motor are both synchronous motors, and once they are started in synchronism, they will run indefinitely in perfect step.

Second, the 8-mm picture prints which are used with this projector, when printed from a standard 24-frame-per-second sound film, are skip-frame-printed to project at 16 frames per second. This means, we

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Continental Products Corporation, 1103 E. 15 St., Kansas City, Mo.

have a picture running at one speed, 16 frames per second, and the sound track on the disk at 24 frames per second, running in synchronism. This 16-frame-per-second speed was chosen for a number of reasons.

It allowed the use of a standard projector speed at 16 frames per second which is the standard speed for taking and showing of 8-mm films. Since many 8-mm cameras will not run at any other speed, it was felt desirable to make the unit project at the standard speed.

It will save film for the amateur. Some amateurs will want to make records to use with their own films, and a recording unit will be

FIG. 1. Movie-Sound-8 unit set up for use.

available soon which will make records with the one-thousand-cycle starting tone. In that case it is desirable that 16 frames per second be used. Experience has shown that amateurs object to photographing 24 frames per second, as they consider that it increases their film cost by 50 per cent.

A saving in film cost can be made in printing library films to be used with the projector.

A one-speed synchronous projector is less expensive to build than a two-speed synchronous projector.

Amateurs who want to add a synchronous motor to their present projectors can do so much more easily if they do not have to think about making it run at two speeds. Such a converted projector will work with the Movie-Sound-8 system.

It is believed that there are a number of advantages to sound on

disk to be used for amateur home use only, and at present, at least, 8-mm is the amateur movie film. Some of these advantages are described in the following paragraphs.

Almost any quality of sound desired by the amateur can be obtained with disks. The art of making electrical transcriptions has been fairly well standardized, and today this method of making delayed broadcasts is used by every radio station in the country.

FIG. 2. Complete unit packs into one case.

Excellent quality can be put on the disk after which it can be played on any type of playback with various degrees of quality. If the amateur wants the best quality of sound with his pictures there is no reason why large speakers, powerful amplifiers, and high-quality pickups cannot be used. On the other hand, inexpensive units giving quality equal to the average home radio can be used.

The Movie-Sound-8 amplifier has a frequency response from 100 to 6500 cycles essentially flat. The crystal pickup and the medium-size speaker necessary for a one-case job naturally limit the quality somewhat. The quality of the $33^1/_3$-revolution-per-minute transcriptions used for the sound track is naturally governed by the quality of the original film recording.

If the amateur obtains his sound from a disk, a turntable is part of the machine and this turntable can run at two speeds. This allows him to play regular 78-revolution-per-minute records, and the unit can be used as a portable phonograph or play records as background music for his own pictures. Since phonograph records are the only common source of recorded music available to the amateur, this is an advantage.

If the amateur desires to add narration to his own pictures, a record can be made with the automatic start tone and the only material cost

will be that of the record. There is no sound film to buy, no processing, no prints. His original film will be the only print he needs. If he desires to change some of his scenes after he has made the sound, he has only to take out the scenes he does not want and add an equal footage of a better scene. Since amateurs do not always secure the scene they desire the first time, this should be an advantage.

Amateurs are used to handling records. Anyone who can thread a projector and operate a phonograph can operate the Movie-Sound 8.

There is no reason why the sound unit cannot be built into a radio-phonograph combination which will work in conjunction with the 8-mm projector, if the Movie-Sound-8 system is used.

The radio-phonograph manufacturer will have to make two changes. A two-speed synchronous turntable is necessary, and the automatic-relay device will have to be incorporated into the amplifier circuit. With such an arrangement a synchronous projector can be plugged into an ordinary radio set, and the amateur can have sound movies at home with no additional expense except that of a synchronous projector.

The Movie-Sound-8 projector is a special unit* driven by means of a chain drive from a $^1/_{40}$-horsepower capacitor start-and-run 3600-revolution-per-minute synchronous motor. The projector runs at exactly 16 frames per second when operated on 110-volt, 60-cycle, alternating current. Any 8-mm projector driven in a similar manner could be used with equal success. An ordinary projector driven by a variable-speed motor will not, of course, work.

The amplifier** is a straightforward alternating-current amplifier, such as is used in a good-quality record player with the selective-frequency relay built into it. The speaker is muted, and is turned on at the same time the projector is started. There is a pilot lamp on the turntable which automatically goes out when the projector starts. A two-speed synchronous turntable is used in the machine. A speed of $33^1/_3$ is used for motion picture projection, and a speed of 78 revolutions per minute for phonograph records. An ordinary silent slide projector can also be used with the unit for showing sound slide films. The amplifier and the turntable motor are both readily removed in case service is needed, and any qualified radio-repair shop can easily make any needed repairs. A selected number of 8-mm sound library

* Built by Eastman Kodak Company especially for the Continental Products Corporation, known as the Kodascope-Eight CPC.

** Built by the Wilcox Electric Company.

films have been released for use with the machine by Castle Films, a Division of United World Films. Any 35-mm or 16-mm sound film can be printed and re-recorded for use with the Movie-Sound-8 unit. In making the negative from which the picture prints are to be made, the skip-frame method is used so that all prints resulting from such a negative will run at 16 frames per second. The sound is recorded on a disk, and pressings of these records are made in the usual manner.

DISCUSSION

MR. A. SHAPIRO: Does the record rotate at $33^1/_3$ or 78 when used with 8 mm?

MR. LLOYD THOMPSON: $33^1/_3$ revolutions per minute.

MR. SMITH: How many feet can you get on one record?

MR. THOMPSON: One ordinary reel by using a 12-inch disk. If you want to use a 16-inch disk it is possible to get two reels on it, which would be equal to 2000 feet of 35-mm sound film.

MR. REED: How many frames do you lose in getting started? In other words, how many frames does it require to start the projector before lip synchronization?

MR. THOMPSON: I cannot tell you how many frames are actually lost in getting the projector started because I have never counted them that way. However the starting characteristic is quite uniform.

MR. JORGENSON: You mentioned that amateurs could cut out portions that were unsatisfactory and splice in better scenes. How do you manage to synchronize words or actions in that case?

MR. THOMPSON: We are not talking about a picture which an amateur might make and record. If you cut out one sequence and put in another you would have to put in the same number of frames that you took out.

MR. JORGENSON: How about the motion of the lips?

MR. THOMPSON: We are still talking about a picture which an amateur might make and record. It is not intended to be used for lip synchronization because it would have to be faked. I do not know of any practical way for amateurs to do lip synchronization with this or any other system. Lip synchronization on library films will of course play in synchronism on the Movie-Sound 8 if they were made in synchronization in the original production.

A NEW SUNSHADE AND FILTER HOLDER FOR 16- AND 8-MM MOTION PICTURE CAMERAS*

JAMES T. STROHM**

Summary.—*This paper describes a new combination sunshade and filter holder which is designed for use on almost any 16- or 8-mm camera. The device is so designed that it not only acts as an adequate light- and sunshade for the camera lens, but by employing a series of slides it will accept gelatin or cemented filters, diffusion disks, gauzes, and pola-screens in various sizes.*

Recently the introduction of a new color-film emulsion by one of the largest film manufacturers in this country again brought to the attention of the 16- and the 8-mm camera users the fact that their cameras were not adequately provided with a means whereby a variety of filters could be used. This new color film, in many cases, required the use of one or two filters for correct color balance. Immediately the problem arose of how these filters could be supplied to the amateur and semiprofessional cinematographer in sizes which could be used on most all of the 16- and 8-mm cameras. The desire to use these special filters in the above-mentioned case, however, was not the only time that this problem has presented itself. Up to the present time, it has been almost impossible for the cinematographer who normally uses 16- and 8-mm cameras to equip himself with any professional type of sunshade and filter holder which would permit him to use standard filters, diffusion disks, pola-screens, and gauzes. This was especially true in connection with filters, because of the fact that they are normally supplied in a variety of standard sizes.

The combination sunshade and filter holder is simply and sturdily constructed and is similar in design to the well-known and standard "matte boxes" which have been used on professional 35-mm cameras for a number of years (see Fig. 1). By employing a series of removable slides the device will accept any filter, diffusion disk, pola-screen, or gauze in the following sizes: 3-inch square, $2^1/_2$-inch round, 2-inch square, and the Kodak Series VI filters. In addition to the numerous filter sizes mentioned above, the device will also accept any gelatin filter, such as Wratten filters, by means of a specially constructed slide. This slide will hold up to four of these gelatin filters which may be cut easily and placed in the slide. The slide is then inserted into a

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Bardwell and McAlister, Inc., Hollywood, Calif.

special slot provided which positions it directly in front of the camera lens (see Fig. 2).

This combination sunshade and filter holder is a universal device and may be used on almost any 16- or 8-mm camera. It is not necessary to drill holes or alter the camera in any way, and the device is so constructed that it is adjustable in all planes and may be correctly centered in front of the camera lens. This is accomplished by providing a camera base which will fit on any amateur or professional tripod.

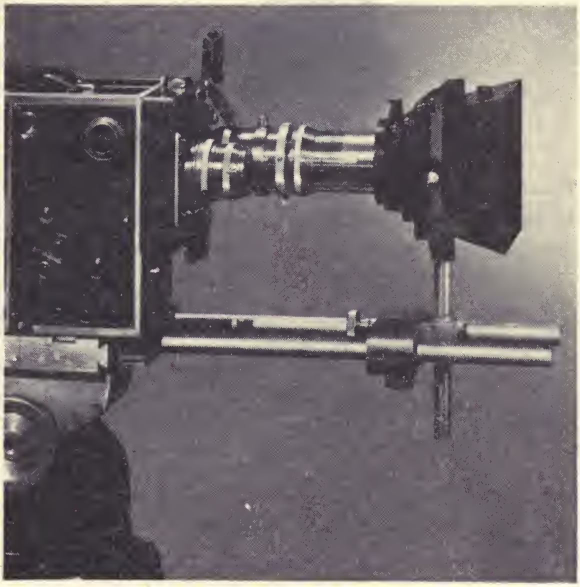

FIG. 1.

The camera is mounted on this base which has a dovetail machined in the casting on the forward edge. The rod assembly which holds the sunshade and filter holder is mounted on this dovetail and can be moved to the right or left as far as desired. All other adjustment movements are accomplished by moving the device up and down on the slide casting and forward and backward on the slide rods. There are a few cameras, however, which are constructed with the viewfinder positioned very close to the photographing lens. This, of course, was done purposely in order to eliminate as much parallax between the photographing lens and the view finder as possible. In these few cases, however, it is only necessary to attach to the sunshade and filter

holder an auxiliary view finder because of the fact that when the sunshade and filter holder are used it obstructs the camera view finder. The device is provided with a boss on the left side upon which an auxiliary view finder may be attached in order to eliminate this difficulty. In such cases an auxiliary view finder can be supplied and is adjustable for parallax and also is provided with a series of mattes to match the field of view of the normally used lenses.

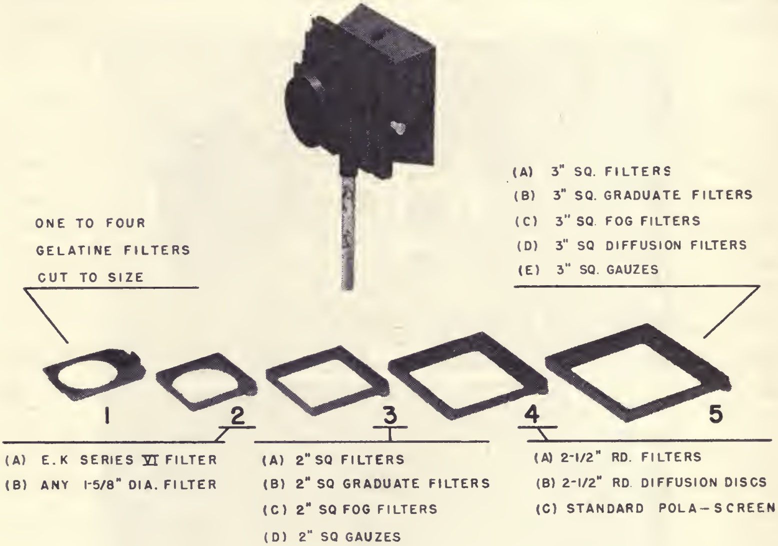

FIG. 2.

Because of the fact that wide-angle lenses are becoming more and more popular for use on 16-mm cameras, the device was designed with an angle of acceptance wide enough to permit its use with a 15-mm lens on a 16-mm camera. The various combinations of filters, gauzes, and diffusion disks which may be used in the device at one time are numerous. It also permits the use of the standard 3-inch square and 2-inch square graduate filters which up until this time have been extremely difficult to use in conjunction with 16- and 8-mm cameras. Besides having the ability to accept a great number of filters of various sizes, the device is finished with a black flock material on the inside of the shade which acts as an excellent light deflector. The device may be used when the camera is hand-held, or in conjunction with a tripod. It is recommended, however, that a tripod be used wherever possible.

METHOD AND EQUIPMENT FOR CHECKING MOTION PICTURE APPARATUS SPEEDS*

C. T. OWLETT**

Summary.—*The operation of a spring-driven motion picture camera is seriously affected if a mechanical tachometer is used to measure the speed. Equipment has been developed and made to give a direct reading of camera speed utilizing a light beam as the connecting link.*

The measurement of the picture frequency of cinematographic apparatus is one of the more important aspects of its manufacture. If the apparatus is powered with a synchronous motor, one need only ascertain that it is operating at synchronous speed. If the power source is a governor-controlled motor of adequate power, the problem is still relatively simple. If a small series-wound motor is used, it is only necessary to make sure that the rheostat adjustment will compensate for variations in line voltage. If, however, the source of power is a flat spiral spring or some similar energy-storage device, it is desirable to be able to study the speed of operation through the entire cycle during which the spring runs down. At the same time this equipment usually has little surplus power for the actuation of timing devices. Several methods have been used in the past, each of which has limitations.

Mechanical-revolution counters are relatively simple and absorb little power but the results must be interpreted by computation and represent only the average speed during a given period of time.

Mechanical or electromechanical direct-reading tachometers will give a continuous indication of speed but there must be available some moving part of the mechanism to which they can be attached and they invariably consume an appreciable amount of power in relation to the amount which is available.

A sectored stroboscopic disk can also be used in one of two ways. This may be rotated by some part of the mechanism and observed by a pulsating light of known frequency. The disk may, alternatively, be rotated at a definite constant speed and illuminated by a light beam that is chopped or otherwise controlled by the shutter or some other part of the mechanism under observation. Special precautions must

* Presented Apr. 23, 1947, at the SMPE Convention in Chicago.

** Eastman Kodak Company, Rochester, N. Y.

be taken to secure very brief light pulses in these cases or the sector pattern appears blurred. A high intensity of ambient light seriously decreases the readability of these devices.

In either of these last two methods one sectored disk will show whether the mechanism is faster than, equal to, or slower than the speed for which the disk is calibrated. Two patterns are satisfactory to indicate whether the speed is at or within definite limits, but will not show the exact speed of the mechanism.

The sectored disk or some part of the mechanism itself can be observed when illuminated by a pulsating light of variable but calibrated

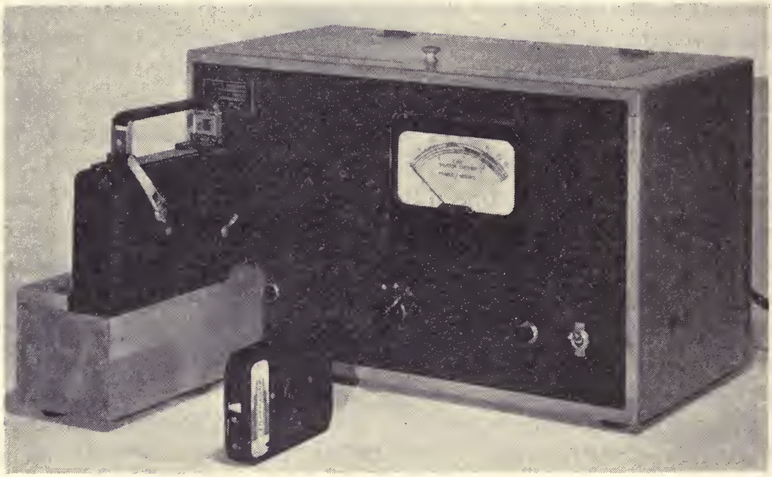

FIG. 1. Cine-camera speed indicator with camera in place for testing.

frequency but this requires adept manipulation if the speed changes as the motor runs down.

One method which produces a permanent record is to photograph with the camera itself a pendulum or some other constant-frequency movement. This requires the processing and analysis of a length of film before the result is known.

A satisfactory instrument to calibrate such apparatus should impose no load on the mechanism, give a direct, continuous indication of the speed, cover all speeds which may be encountered (8 to 64 frames per second), and have a linear scale.

Fig. 1 is a photograph of a device which has been built to meet these requirements and does so quite closely. It is a rectangular cabinet 10

inches high, 15 inches wide, and 8 inches deep. At the left side of the face is a one-inch diameter hole against which the apparatus which is being checked is placed. At the right is a meter with a multiple scale, calibrated in frames per second. Along the bottom are a telltale light a range-selector switch, a push button for calibrating at 60 cycles per second and an on-off switch. Adapters are provided to accommodate the various cameras.

Fig. 2 is a photograph from the rear of the panel with the case removed. This shows the major electronic and optical elements. The

FIG. 2. Rear view of chassis.

potentiometer knob directly behind the meter is used in adjusting the calibration.

Fig. 3 is a block diagram of the optical and the electronic systems. Light from a 6- to 8-volt, 15-candle-power lamp S passes through a half-silvered plate M which is set at an angle of 45 degrees. The transmitted light is converged by a simple condenser lens L into the aperture of the apparatus which is being checked. If the film-pressure plate in the camera is not bright or if the camera is being checked with film, a bright reflecting surface must be provided in the aperture. As the camera shutter opens the light is reflected back through the

condenser L to the half-silvered plate M and a portion of this light is reflected to the cathode of a phototube C. As the shutter closes, no light reaches the phototube.

The output of the phototube is fed to a 6SJ7 pentode whose internal plate resistance serves as the grid return of one half of an Eccles-

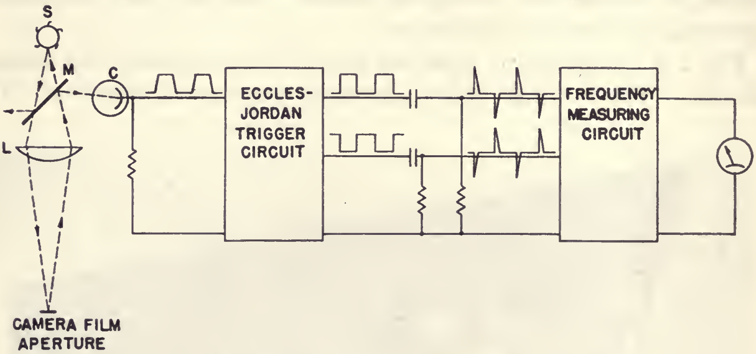

FIG. 3. Block diagram of cine-camera speed indicator.

Jordan trigger circuit using a 6SN7 twin triode. One unit conducts when the shutter is open, the other when the shutter is closed. The plate voltage of each unit is a series of rectangular pulses of constant amplitude, one positive when the other is negative. The only variable is the frequency which is that of the shutter.

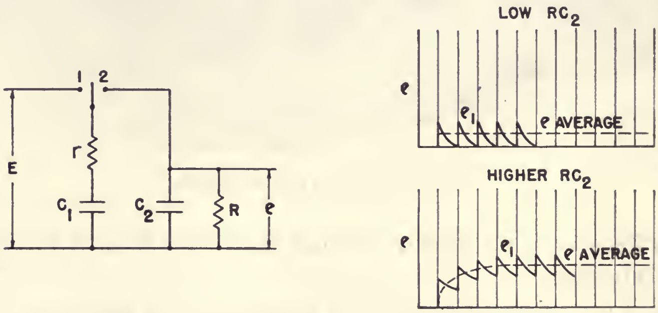

FIG. 4. Frequency-measuring circuit.

These rectangular pulses which vary in frequency with that of the camera which is being calibrated are changed by resistance-capacitance differentiating networks into spiked trigger pulses which are fed into a frequency-measuring circuit. The output of the frequency-measuring circuit is a voltage which is dependent on input frequency and is read on the calibrated scale on the face of the instrument.

The most interesting part of the entire unit is the frequency-measuring circuit which is shown in Fig. 4. This includes two 2050 thyratrons which act as a single-pole double-throw switch, shown symbolically at 1, 2.

This switch is closed in one direction or the other as controlled by the two sets of trigger pulses. One of these provides a positive trigger pulse to one thyratron when the shutter opens, the other does the same to the second thyratron when the shutter closes. The negative pulses may be ignored as their magnitude is less than the ionization potential of the thyratrons they control.

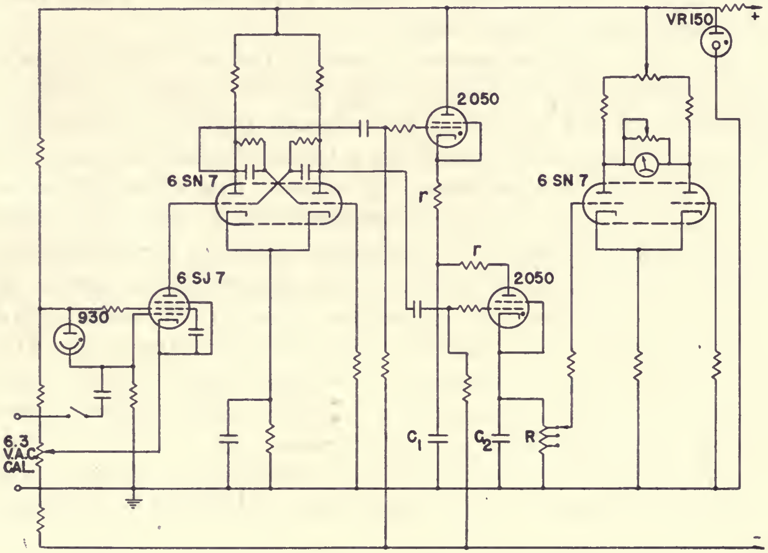

FIG. 5. Schematic diagram of cine-camera speed indicator.

The first thyratron, fired by the shutter-opening pulse, charges C_1 in its cathode circuit through a current-limiting resistor r to a fixed voltage equal to the regulated supply voltage less the tube drop. When the cathode reaches this potential, the negative grid regains control. The time constant rC_1 is so small that the thyratron is always deionized before the shutter-closing trigger pulse arrives. This pulse fires the second thyratron and throws the switch to position 2, which discharges C_1 into the much larger capacitor C_2 shunted by a resistor R. This is repeated each time the shutter opens and closes.

The average current through R is $i = fC_1(E - 2d - e_1)$, in which f is the shutter speed in frames per second, E is the supply voltage, d is the voltage drop in each thyratron, and e_1 is the peak voltage developed across C_2 as C_1 discharges. The average voltage $e = iR$ is measured by a vacuum-tube voltmeter calibrated in frames per second.

If the time constant RC_2 of the output circuit is reduced so that C_2 is always discharged between pulses, e_1 is reduced to a small constant dependent on the ratio of the two capacitances. The calibration is then linear with frequency and the response to a change in frequency is immediate. The voltage would be in the form of a series of pulses with a sharp rise and an exponential decay. At the slower shutter speeds, a meter with normal damping would tend to follow these pulses rather than average them.

As the RC_2 product is increased to smooth out the voltage across C_2 and reduce the needle vibration of the indicating meter, e_1 increases with frequency and a drooping characteristic is given to the calibration curve. A lag in response is also introduced which increases with the RC_2 product. A detailed analysis is given at the end of the paper.

The circuit for the instrument is shown in Fig. 5. Since the slowest shutter speed in general use is 8 frames per second, a compromise was adopted which gave a reasonably steady deflection at 5 frames per second without unduly slowing down the response of the meter. With a suddenly applied signal, the time required to reach 99 per cent of the final deflection is about 1.5 seconds. On higher ranges it would be advantageous to increase the speed of response. This could be done in the range switching by progressively decreasing R.

In later models a thermal time-delay switch will be incorporated to supply plate voltage to the thyratrons after all cathodes have warmed up.

APPENDIX

Analysis of Frequency-Measuring Circuit

In this analysis, the two thyratrons are replaced by a single-pole double-throw switch thus neglecting the voltage drop in the tubes. It is also assumed that when the switch is closed in position 2, the voltage across the capacitors reaches an equilibrium instantaneously. This is justified at the frequencies in which we are interested since the time constant is of the order of a few microseconds.

Assume for the moment that the resistor R shunting C_2 is removed, that C_2 is charged to a voltage e_A and C_1 to a voltage E. The charge on C_1 is EC_1, that on

C_2 is $e_A C_2$. If the switch is now closed in position 2, the capacitors are in parallel and the charges are redistributed so that the voltage across C_2 is now

$$e = \frac{EC_1 + e_A C_2}{C_1 + C_2} = \frac{EC_1}{C_1 + C_2} + \frac{e_A C_2}{C_1 + C_2} = E\frac{C_1}{C_1 + C_2} + e_A \frac{C_1}{C_1 + C_2}\frac{C_2}{C_1}.$$

If we let $\dfrac{C_1}{C_1 + C_2} = K$ and $\dfrac{C_2}{C_1} = N$, this reduces to

$$e = K(E + Ne_A). \tag{1}$$

If resistor R is now replaced, the capacitor will begin to discharge through it so that after any time t, the voltage will be $e = K(E + Ne_A)\epsilon^{-t/RC_2}$. Since the discharge period will always be the time to complete one cycle, $t = 1/f$, so

$$e = K(E + Ne_A)\epsilon^{-1/fRC_2}. \tag{2}$$

Equations (1) and (2) will enable us to determine the transient and steady-state response of the circuit to any frequency.

Initially, C_1 is charged to a voltage E and C_2 has no charge. The switch starts vibrating at a frequency f. As it closes in position 2 the first time, the voltage across C_2 becomes $e = K(E + NO) = KE$, and the switch returns to position 1 to recharge C_1 to a voltage E. After a time $t = 1/f$, the voltage across C_2 will have dropped to $e = K(E + NO)\epsilon^{-1/fRC_2}$ and the switch is ready to close in position 2 for the second time to add another increment of charge.

The value of e over several cycles will be derived. Column A gives the value of e after the 1st, 2nd, ... closure of the switch in position 2. Column B gives the value to which e has dropped just before the 2nd, 3rd, ... closure in position 2.

	A	B
(1)	$e = K(E + NO) = KE$	$e = KE\epsilon^{-/CfR_2}$
(2)	$e = K(E + NKE\epsilon^{-1/fRC_2})$	$e = KE(1 + NK\epsilon^{-1/fRC_2})\epsilon^{-11fRC_2}$
	$= KE(1 + NK\epsilon^{-1/fRC_2})$	$= KE\epsilon^{-1/fRC_2}(1 + NK\epsilon^{-1/fRC_2})$

To simplify the notation,

$$\text{let } NK\epsilon^{-1/fRC_2} = r.$$

Then

(2)	$e = KE(1 + r)$	$e = KE\epsilon^{-1/fRC_2}(1 + r)$
(3)	$e = K(E + NKE\epsilon^{-1/fRC_2}(1 + r))$	$e = KE\epsilon^{-1/fRC_2}(1 + r + r^2)$.
	$= KE(1 + r(1 + r))$	
	$= KE(1 + r + r^2)$	

It may be seen that the value of e in each of the equations A and B is the sum of a geometric series of the form $a + ar + ar^2$..... The ratio r in both cases is $NK\epsilon^{-1/fRC_2}$ and since it is always less than 1, the series is converging.

The limiting value of such a series is $s_{\text{inf}} = a/(1-r)$ while the sum of a finite number of terms n is $s_{\text{fin}} = a(1 - r^n)/(1 - r)$. The fraction of the limiting value reached after n terms is

$$\rho = s_{\text{fin}}/s_{\text{inf}} = \frac{a(1 - r^n)/(1 - r)}{a/(1 - r)} = 1 - r^n$$

To find the number of terms required to produce a given ρ, we have $r^n = 1 - \rho$ or $n \log r = \log (1 - \rho)$

$$n = \log (1 - \rho)/\log r.$$

The time corresponding to n cycles is $T = n/f$ so

$$T = \log (1 - \rho)/f \log r.$$

The indicating voltmeter responds to the average voltage across C_2. The average voltage across a capacitor discharging through a resistor for a time t is

$$e_{av} = \frac{E_0 \int_0^t \epsilon^{-t/RC_2}}{t} = \frac{E_0(-RC_2)(\epsilon^{-t/RC} - 1)}{t}$$
$$= \frac{E_0 RC_2(1 - \epsilon^{-t/RC_2})}{t}$$

since $t = 1/f$.

$$e_{av} = E_0 f RC_2(1 - \epsilon^{-1/fRC_2}).$$

E_0 corresponds to the e in column A above. The output voltage (steady-state) at any frequency is then

$$e_{av} = \frac{KEfRC_2(1 - \epsilon^{-1/fRC_2})}{1 - NK\epsilon^{-1/fRC_2}}.$$

In the instrument just described the following values were used in the frequency-measuring circuit:

$C_1 = 0.0025$ microfarad $R = {}^1/_3$ megohm
$C_2 = 1.000$ microfarad Supply voltage $= 152$ volts Drop in each thyratron $= 8$ volts

$K = \dfrac{0.0025}{1.0025} = 0.00249$ $NK = \dfrac{1.0000}{1.0025} = 0.9975$ $E = 152 - (2 \times 8) = 136$ volts.

At a speed of 60 frames per second, $\epsilon^{-fRC} = \epsilon^{\frac{-3}{60 \times 1}} = \epsilon^{-0.05} = 0.951$. The time required to reach 99 per cent of the steady-state output voltage is

$$T = \frac{\log (1 - 0.99)}{60 \log NK \times 0.951} = \frac{-2}{60 \times (0.0229)} = \frac{2}{1.375} = 1.45/\text{second}.$$

The output voltage is

$$e_{av} = \frac{0.00249 \times 136 \times 60 \times {}^1/_3(1 - 0.951)}{1 - (0.9975 \times 0.951)} = 6.58 \text{ volts}.$$

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CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

28, 8 (Aug. 1947)

A New Color Tester for 16-Mm Kodachrome Duplication (p. 275) W. Leahy

Historical Development of Sound Films. Pt. 2 (p. 280) E. I. Sponable

The Cinema Workshop. 14. Screen Makeup (p. 284) C. Loring

British Kinematography

11, 1 (July 1947)

British Influence in the Technical Development of Kinematography (p. 1) R. H. Cricks

Films in Aircraft Manufacture and Testing (p. 14) J. C. Thackery

Electronics

20, 9 (Sept. 1947)

A New Television Projection System (p. 84) W. E. Bradley and E. Traub

Ideal Kinema

13, 145 (Aug. 14, 1947)

Further Adventures in Stereoscopic Kinematography (p. 21)

International Projectionist

22, 8 (Aug. 1947)

What Makes a Good Loudspeaker? (p. 5) R. S. Lanier

Increased Light for 16-Mm Projection (p. 8) E. J. Zavesky and W. W. Lozier

Historical Development of Sound Film. II. The Work of Case and de Forest—1911–24 (p. 10) E. I. Sponable

Trucolor Only Acetate Releases 'til 1948; Splicing and Focusing Data (p. 12)

DeVry 12,000 Series 35-Mm Sound-Film Projector (p. 14) E. W. D'Arcy

New Kolograph Sound-Film Projector (p. 18)

Journal of the Institution of Electrical Engineers

94, Pt. III, 30 (July 1947)

The Design of High-Fidelity Disc Recording Equipment (p. 275) H. Davies

Kinematograph Weekly

365, 2099 (July 24, 1947)

Let's Make 19-Mm the Standard for Our Narrow-Gauge Films (p. XIX) R. H. Cricks

Philips Technical Review

9, 3, (1947)

Problems in Photographic Reproduction, in Particular of Sound-Films (p. 65) C. J. Dippel and E. J. Keuning

PSA Journal

13, 8 (Aug. 1947)

Equations for Calculating the Condition of Photographic Solutions in Continuous Systems (p. 494) R. W. Henn and M. Hershberger

Radio News (Radio-Electronic Engineering)

38, 3 (Sept. 1947)

Television Counters (p. 52) E. M. Noll

Reflective Optical Systems for Projection Television (p. 54) V. K. Zworykin

The Recording and Reproduction of Sound. Pt. 7 (p. 62) O. Read

SOCIETY ANNOUNCEMENTS

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Manuscripts should be accurate, concise, and carefully checked, both technically and grammatically. They should be submitted in duplicate, an original copy on plain white paper and the copy on onion skin. They should be double-spaced, with adequate margins on all four sides. References should be complete, and should appear in the order of their introduction in the text. Line drawings should be in black ink on strong white paper or blue draftsman's linen. Where cross-hatched paper is used, it should be with a blue background and with the major divisions in black or red. If log-log paper is used, it is necessary to redraw the diagrams, with only the major divisions indicated. Co-ordinate paper with brown, yellow, green, or red divisions makes very poor cuts, since in the photoengraving process these colors come out black, and are generally splotchy, so that unsatisfactory results occur.

Photographs should be glossy prints, with all details sharp and clear. Line drawings should be $8^1/_2$ by 11 inches in size and photographs should be the standard 8- by 10-inch prints. Printing should be uniform and large enough to reduce to one third the size of the original illustration. Each figure should be plainly marked on the margin—not on the figure itself. Captions should be typed up on a single sheet of paper. Figures should be introduced into the text in order.

A summary should introduce the subject matter. If the paper has been presented, a notation to that effect should be made.

In accordance with the usual practice of most technical organizations, the SMPE does not pay for manuscripts. Once submitted, the paper becomes the property of the Society, and the editorial readers may make changes in the script, if they deem it necessary. The author will have an opportunity to accept or reject these suggestions as he sees fit.

Manuscripts should be sent to

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State of New York }
County of New York } ss.

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Boyce Nemec, who, having been duly sworn according to law, deposes and says that he is the Executive Secretary of the *Journal of the Society of Motion Picture Engineers* and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily, weekly, semiweekly, or triweekly newspaper, the circulation), *etc.*, of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Acts of March 3, 1933 and July 2, 1946 embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

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BOYCE NEMEC, Exec. Secy., Business Manager.

Sworn to and subscribed before me this 13th day of October, 1947.

(Seal) Elisabeth J. Rubino
Notary Public, Clerk's No. 2986,
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(My commission expires March 30, 1949)

SOCIETY of MOTION PICTURE ENGINEERS

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JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS

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MY FIRST FIFTY YEARS IN MOTION PICTURES*

OSCAR B. DEPUE**

Summary.—*This is an intimate, chronological account of the author's experiences as a partner of the world's leading travelog exponent, Burton Holmes. Their first meeting is described in 1893 as well as their world-wide wanderings through the years up to 1917, and the problems encountered in devising camera, developing, projection, and film-printing equipment in those early days. The period from 1917 to date is concerned with the establishment of the Burton Holmes Films Laboratory, the theatrical release of a weekly travelog for six years, and the author's invention and manufacture of 35-mm and 16-mm printers and automatic light-control boards.*

In 1887 I was employed by the McIntosh Battery and Optical Company in Chicago, a firm operated by Dr. McIntosh, inventor and designer of many electrical and optical devices for the medical profession. The doctor gave many lectures before medical students and medical conventions. Work with him gave me the opportunity to learn the art of slide projection, microscopic work, and the handling of battery appliances and static machines for doctors' offices.

Ultimately, in addition to assisting Dr. McIntosh, I became a projectionist for other doctors and for various public lecturers. I was frequently sent out of the city and my ingenuity was taxed in overcoming the difficulties of installing projectors and screens in a wide variety of halls, churches, and theaters which, at that time, had little equipment of their own. The illumination for stereopticon projectors was the calcium light. In fact, this was the only illumination even up to the time of motion pictures, and we used it for them during the years of 1897, 1898, and 1899.

It was while working with Dr. McIntosh that I first met Burton Holmes, who was searching for someone to project some lantern slides that he had made in Japan in 1892. He had brought back enough snapshots of the country to give an evening's entertainment or lecture on his travels. For his initial tryout on the Chicago public, he rented

* Presented Apr. 21, 1947, at the SMPE Convention in Chicago.

** Oscar B. Depue and Burton Holmes Films, Inc., Chicago, Ill.

the recital hall on the seventh floor of the Auditorium building, counting quite heavily on his family's acquaintanceship with many of Chicago's society leaders.

This tryout in November, 1893, The World's Fair year, was a complete success—even with only the four performances planned. The hall seated about three hundred and fifty persons, and before the series was completed, the audience was sitting on camp stools in the aisles. That was the beginning of my association with Burton Holmes which eventually led to motion pictures and my work today.

In 1895 I traveled in Europe taking still pictures with Mr. Holmes. The trip was a bicycle tour through England, France, Corsica, Italy, and Switzerland. The pictures were made into hand-colored stereopticon slides which we showed in the winter at lectures in an ever-widening circle of cities.

In 1896 we realized that we had a growing rival—the motion picture. As a result, in 1897, at the end of the 1896 season, Mr. Holmes sailed for Sicily and Italy and I sailed for London, the Mecca for motion pictures at that time. My intention was to search out and buy a motion picture camera. I found little from which to choose, and the prices were exhorbitant. I was forced to go to Paris to see what I could find there. The situation was almost as bad—with one exception. Mr. Leon Gaumont had a Demeny camera for 60-mm film—the only machine that I could find in all of Paris. It was not what you would call a facile piece of apparatus; it was cumbersome and its tripod was a piece of two-inch plank fitted with solid iron legs (not adjustable). I was somewhat fearful of what I could do with this equipment, but nevertheless I purchased it and took the first train to Rome to join Mr. Holmes.

It was there that I made my first motion picture exposure. I chose St. Peter's Cathedral and the great Piazza with its obelisk and fountains as a subject—a subject, I admit, that lacked animation until a herder with his flock of goats passed in front of the fountain to give it movement.

It may seem ridiculous now to consider that then I thought I must always have some famous background for my motion pictures. I had not quite broken away from still photography enough to realize that movement was the chief function of motion pictures.

That photographic expedition led me to Naples, Venice, and Milan and then up to Paris again where I took just one motion picture. This was of the Place de la Concorde—a scene that had *real*

animation. I secured the picture by planting a cab at the busiest place in the Concorde. With the driver's seat for my tripod, I was able to photograph the teeming traffic at close range. The police remonstrated with me vigorously for blocking traffic, but I "failed to comprehend" what they were after until I had finished what *I* was after—fifty feet of picture.

This negative and those made previously in Italy were taken to the Gaumont studio for development. I left the negatives with them in exchange for one print from each. Some fifteen years later, Mr. Gaumont graciously sent us these negatives, which are now in the Burton Holmes Films' storage vaults.

My next step was to return home and start to get equipment together for developing, printing, and projecting these motion pictures and others that I was soon to make of New York, Yellowstone Park, and other points of interest.

En route, I stopped in Rochester to visit the Eastman Kodak Company and had an interview with Mr. George Eastman. He agreed to cut film, both negative and positive, in a 60-mm width for me. He also gave me some ideas of how he thought I might build a printer.

I did build the printer, following his ideas and some of my own. It was a very amusing gadget when I look back at it today. The printer was mounted on a wall in a darkroom, with a hole through the wall to admit the exposure light from a lamp in the next room. The lamp was mounted on a rod so that I could slide it nearer or farther away from the film to suit the density of the negative which was observed as it passed in front of a slit. The lamp, mind you, was a Welsbach gas lamp—no such luxury as the electric light which came two years later.

The major problem of providing power to operate the printer was solved with a small water-wheel motor that I attached to the water faucet in my basement. This power, little as it was, was sufficient to drive the printing machine and a film perforator which I built as well. All this equipment had to be completed in time to have the films ready to be shown in the fall of 1897.

In addition, I had to convert the Gaumont camera into a projector. It proved to be quite satisfactory. The motion pictures were shown after Mr. Holmes' lecture proper, as a fifteen- or twenty-minute added attraction. With the spontaneous outburst of applause that followed the first roll, we had the great satisfaction of feeling that it was a real success, which, indeed, it proved to be during the rest of the season. As far as I know, these programs in the fall of 1897 marked the first

time that motion pictures were used by any public lecturer in this country.

By the end of the 1898 season, I had constructed a larger camera which would accommodate 200-foot rolls of negative. I also made some improvement on a portable tripod. This equipment was taken to the Grand Canyon of the Colorado for the *first motion pictures* made of that great sight.

We then went on to Honolulu for a tour of the Hawaiian Islands. The American troops were passing through Honolulu on their way to Manila, for the Philippines had come into our possession through Dewey's victory at Manila Bay.

Returning from Hawaii, we stopped again at the Grand Canyon to make more footage and also visited the Hopi Indians' snake dance at Oraibi to make the very first motion pictures of such a ceremony. One year later I returned to photograph a snake dance at Walpi, the largest of the region's villages.

This second visit afforded an opportunity to show the Indians the pictures taken the year before so, on my way back to Canyon Diablo to take the train for home, I spent a few days at an Indian trading post called "The Lakes" run by Mr. Volz. My projecting equipment, a calcium-light outfit, and tanks of oxygen and hydrogen had been sent out in advance. Through Mr. Volz's co-operation, we gathered an audience which I believe was the most interesting I've ever seen. We set the projector in the back end of a lumber wagon and attached the screen to the side of the trading post. Several hundred Indians squatted around in circles on the ground waiting for something to happen.

In addition to the snake-dance pictures, I had photographed some Indian sports at the same location. One of these was called a "Gallo Contest." A rooster was buried up to its neck in sand, then the riders swooped past, leaned down, and attempted to pluck it from the ground without falling from their horses. You could hardly call this a humane sport, but it was the Indians' idea of fun—not mine. And you can imagine the reaction of my audience, who had never seen movies before, when they saw their own actions reproduced on the screen.

Another "sport" which I had photographed was the pursuit of a white girl on a fleet pony by a band of one hundred mounted Indian braves. The Indians entered into the chase with such zeal that I feared for the girl's safety and that of my camera as they raced by at full tilt. This part of the film made a hit too—but the high spot of the

evening came with a mad scramble away from the screen when I showed pictures I had made of the Empire State Express dashing toward the camera, and of the Omaha Fire Department in action. Seats "front and center" went begging after that, but finally the Indians' fears were allayed and the show went on.

One of the pictures taken the year before showed a storekeeper of the post who had since died. There was a shout from the Indians when they saw him and his dog on the screen. The "magic" of the movies made fans of them very quickly and the next time I wanted to film their games, I had no trouble in obtaining the assistance of the whole tribe. When the show was over, the audience was curious to know where the pictures came from; they touched the screen and looked behind it, but strangely enough paid no attention to the projector in the wagon.

In 1899 I built a new camera with a capacity of 400 feet of negative. It had some modern conveniences such as a footage counter, a punch for marking scenes, and a film magazine which allowed loading and threading of the camera in daylight. However, in unloading, the film had to be removed from the camera in a changing bag, or in the darkroom. I had also built an improved projector which was patented on April 4, 1899.

In 1900 I spent my time building a portable developing outfit for a trip around the world. This trip, in 1901, took us first to Berlin, Warsaw, St. Petersburg, and then to Moscow where the trans-Siberian railway journey started. Before leaving Moscow, however, I hired some carpenters to make the wooden tanks to go with the developing racks which I had made at home—but the difficulty I experienced in getting the work done and the poor workmanship convinced me that I should wait until we reached Japan before building the drying racks which I also needed. There I found clever carpenters who constructed them quickly Each rack held 200 feet of 60-mm film, and weighed twelve pounds. They folded down to fit into a box about four feet long and ten inches square.

The journey across Siberia was a memorable one. The trans-Siberian railroad only extended as far as Stratensk, a town three days' travel beyond Lake Baikal. After waiting there for several days, we secured passage on a river steamer for the first leg of a long journey down the Shilka and Amur rivers to Khabarovsk. The steamer stuck on the first sand bar, so we were transferred to one of shallower draft. We were on many boats before the trip was finished; in most

of them we had to sleep on the upper deck—if there was one. Many of these craft were open barges. They got stuck the same as the steamer so on several occasions we were obliged to change to other barges with less draft. Each transfer lightened the load of the one that was stuck, so that it could be floated again.

We were twenty-eight days on this river trip, but finally we landed at Khabarovsk and proceeded by rail to Vladivostok. As soon as passage could be secured, we took a steamer to Nagasaki and from thence to Korea where we visited Fusan and Seoul, the capital.

From Seoul we went to Peking where the Boxer Rebellion had just been subdued. We saw troops of all the allies that took part in the siege—they were still there and in other parts of China. It was an opportune time for our visit because we were allowed, through the aid of our own troops, to see and film things that might not have been available to us otherwise. For instance, a company of American troops from Indiana guarded the north half of the Emperor's Palace in the Forbidden City. Japanese troops were stationed at the south half—our allies at that time—if not forty years later.

We sailed from Chefoo, China, returning to Nagasaki again where we took the train to Tokyo. We made a number of pictures in Japan, and in September I set about developing them and all the rest taken since leaving Moscow. I was permitted to use the old clubhouse of the Yokohama club near the Grand Hotel. The developing caused little difficulty, but the question of drying the film in that very damp and heatless building was a critical one. I had film looped all over the place. It refused to dry thoroughly and finally I was forced to coil it up the best I could in order to sail on the *Coptic* for America. I finished the drying job in my stateroom aboard ship. This experience and previous ones convinced us that our 60-mm films were more difficult to handle than the smaller 35-mm that had become standard. In addition, by being off-standard, we could not always obtain film when we needed it, nor could we sell our wide film to the trade. In short, the 60-mm was passé.

The next year, 1902, I purchased a 35-mm Bioscope camera from the Warwick Trading Company in London and put it to work on our tour of Norway, Denmark, and Sweden. It was in Norway that I conceived the idea of making single-frame exposures at intervals to speed up the action seen from the bow of our steamer as it sailed through the turning, twisting fjords of that beautiful country.

In Bergen, I found a watchmaker who made me a small crank which

was attached to the camera's pull-down mechanism in such a way that a single turn of the crank exposed one picture. By closing the shutter to a mere $^1/_8$ inch wide, the exposure was about right although it depended on the speed at which the crank was turned.

Thus equipped, I planted my camera in the very bow of a steamer and by carefully observing the steamer's movements as it went straight ahead or turned for the bends in the fjords, I could increase or decrease the number of exposures to fit the apparent movement of the foreground. This first experiment, made on a short trip from Vick to Ulvick, proved quite satisfactory, but before ending our Norway trip at Christiania (Oslo) I had a chance to make a "fast" motion picture that turned out to be very successful. It showed a series of seven locks, with our steamer going into the top one and down through all the rest, then sailing away. By making single exposures at proper intervals, the action was condensed to a very short time on the screen. I really had to scramble to get the picture and then board the steamer again.

That picture was probably the first example of that type of cinematography—which we called "crazy pictures." It so impressed the Bioscope people that one of the principals, Mr. Charles Urban, asked us to leave the negative with him so that he could sell prints on a royalty basis. It was not a bad deal for us because many prints were sold. The short fjord picture was used also.

Several years later (in 1907) I made another trip to Norway and took "crazy pictures" the whole distance of a fjord journey of 120 miles. It was shown in about three minutes on the screen and gave a very good impression of such a journey. By this time I had constructed a shutter and crank that equalized the exposures. They no longer depended on how fast the crank was turned; the shutter, similar to a focal plane shutter, was activated by a spring which always gave the same exposure.

In 1903 we toured Alaska, taking the railroad over the White Horse Pass to White Horse, and then a stern-wheel steamer down the Yukon to Dawson. There we filmed the gold miners and their sluicing and hydraulic operations. During the remainder of our journey down the Yukon and on to Nome, we traveled and slept on a barge lashed to a river steamer. Returning from Nome to Seattle on the *Ohio* we passed through the Aleutian Islands with never a thought that they would one day be the scene of fierce encounters between Japs and Americans.

In 1905 we visited Germany and Austria again. We also visited

Ireland, touring leisurely by jaunting car. This acquainted us with the country much more intimately than the usual trip by rail.

In 1906 we made an extended trip through Egypt, going up the Nile on a private yacht to the town of Wadi Halfa near the second cataract. On the way we visited the Valley of the Tombs of the Kings, the Temples of Luxor, and the Pyramids. We climbed Cheops, the largest Pyramids, and photographed other American tourists as they struggled up those great three-foot steps. All the films taken in Egypt were developed in Shepherd's Hotel in Cairo—a wonderful place at a wonderful time of the year—the last part of March.

Next we sailed for Italy, arriving in the Bay of Naples on April 8, just as the famous eruption of Vesuvius took place. This was the largest eruption in 300 years and it blew off the whole top of the mountain. We went ashore as soon as possible, secured hotel accommodations, then drove some fourteen miles to the base of Vesuvius. There we saw the great flow of lava which came down from its sides. The lava was engulfing and burning the homes of farmers and villagers. Part of the lava had cooled sufficiently to allow us to scale it and just as darkness came on, the lightning played around the top of the mountain, creating a wonderful display. Simultaneously we became aware of a veritable snowstorm of ashes falling on us, so we turned toward Naples in a hurry. The drive back through the blinding ash storm was a terrifying, wearying experience.

When we finally got back to our hotel, we found that only three guests remained out of about eighty that had been staying there that morning. The rest had left to get as far away as possible. That night two inches of ash fell on Naples and tremendous quantities fell on the slopes of Vesuvius.

We set sail from Brindisi for Greece and went by rail from Patras to Athens where the Olympic Games were being held. A memorable thing about the rail journey was that passengers getting on at a way station had Greek newspapers telling of another great tragedy caused by nature—the San Francisco earthquake and fire.

Filming the Olympic Games was a pleasant task. One of my best pictures was of the high-diving contest at Phalaron. Among the contestants was Annette Kellerman making her European debut and besides putting on a marvelous exhibition, she created a stir by introducing the one-piece bathing suit. Even though the suit was perhaps two or three times larger in area than those we see at the beaches today, it was considered very daring in that day and age.

We returned to Naples where I searched for a suitable darkroom in which to develop the Olympic Games pictures. I found a small photographic studio operated by a young Austrian who rented it to me for a few days so that I could set up my portable developing machine. The ashes from Vesuvius were still falling and I had considerable trouble in keeping the films clean.

This young Austrian offered to assist Mr. Holmes in photographing around Naples when it became necessary for me to return to Chicago. He became intensely interested in motion picture work and asked Mr. Holmes how he might go about getting into it on a permanent basis. Mr. Holmes gave him a letter of introduction to Mr. Charles Urban in London. The young man spent several weeks studying English to prepare for the interview, only to find that Mr. Urban spoke German as well as he did.

The young man was hired and in four weeks time absorbed all that the Bioscope Laboratory could teach. Then Mr. Urban sent him to South Africa to make motion pictures of the diamond mines at Kimberley and the great Victoria Falls of the Zambesi River. The films that he sent back were excellent in quality; no detail had been overlooked in the taking and packing. Urban was so pleased that he sent the young man to India at the time of the Durbar to photograph the processions and ceremonies of the Coronation in Kinema-color—probably the first great event ever photographed in color. I saw these films at the Alhambra in London where they ran for over a year.

You may wonder who this young man is. I think that most of you know him—Joseph De Frenes—who today has a motion picture production business in Philadelphia.

I have mentioned previously the second trip to Norway in 1907 to make another film of the fjord trips. It was on this trip that I purchased a Poulson wire recorder in Copenhagen. It was driven by a direct-current 110-volt motor, and so I was able to operate it in my steamer cabin while en route home. I had a lot of fun talking into it and playing back, and soon had a procession of passengers eager to record and hear their own voices. Several theatrical notables were present, including the famous Jimmie Powers who had just finished a London season. He was full of hit songs and stories, so we recorded a few. When he finished, I spoke into the recorder saying that Powers' record was made on the twenty-eighth day of August, 1907, in mid-ocean aboard the *S.S. Augusta Victoria*.

Thirty years later, aided by Walter Hotz, Burton Holmes Films'

sound engineer, I re-recorded Powers' voice on film. The wire had retained the record as clearly as when it was first made. When amplified, it appeared to have lost none of its original quality, although it may have lost some volume.

This re-recording was presented to the Society of Motion Picture Engineers at a time when wire recording was again in the limelight. Today there is a strong possibility of its having widespread use in the film industry.

In 1908 we made our second world tour, going first to Hawaii, Japan, and China. From Hong Kong we took a Dutch freighter to Java, a voyage of eight days. The ship was manned by seven or eight Hollanders and a Malay and Chinese crew. The other passengers, besides the two of us, were two Japanese and two hundred and fifty coolies on their way to work in the tin mines on the Isle of Banka just off Sumatra.

One day some petty incident caused a near riot which had us fearing for our lives until the Hollanders put the whole lot down the hatchway and fastened down the cover. It sounds easy when you tell it, but it took a lot of "doing." It was very interesting to watch a handful of men handle a mob of two hundred and fifty coolies without bloodshed. They used a number of sticks which landed where they did the most good and thus achieved order again—much to our relief.

From Banka we took a little coastal steamer for a two-day run to Batavia, Java. The craft was so crowded with Javanese, Chinese, and Japanese that it was difficult to find a place to sleep on the deck.

Sometimes things were not only different, they were difficult. This was especially true in regard to our photographic equipment. For instance, Mr. Holmes had a Gaumont 9- × 12-cemtimeter hand camera with a delicate shutter which failed as soon as we started photographing in Batavia. One of the leaves of the shutter had broken. It took a gunsmith three days to make a new one which, after half a day's photographing, broke too. I decided that this time I would do the fixing. A tin can provided material for a new leaf. In my developing kit was a small Godell Pratt drill which I clamped to a table so that it served as a turning lathe. I turned out a couple of rivets from brass pins, and attached the leaf to the shutter and then blackened it. Strange as it may seem this improvised shutter served very well for the rest of the tour and the resulting pictures were as good as those made before the mishap. From that time on I carried an ample tool kit which proved its worth many times.

Developing film in Java was another problem. While in Batavia, we stayed in a "hotel" bungalow which had a square concrete bathtub which I used for developing, but I had to wait until two o'clock in the morning for sufficient coolness. Even then the water was never cooler than 86 degrees for it came from a tank in the patio exposed to the hot sun during the day. The tank was filled by coolies who carried the water from a well some distance away.

I solved the problem by using ice, which was a scarce item, to cool the developer. I could never get enough for the hypo and wash too, so I fixed the film hurriedly, and gave it a short rinse, thus avoiding loosening of the emulsion. When we returned to the United States, I refixed and rewashed all the film and lost none as a result of it all.

The discomfort and inconvenience of the heat in Java in midsummer were compensated for by the interest that the country provided. Our round-trip railroad journey took us from one end to Soerabaja at the other. We passed many beautiful terraced rice fields on the mountainsides and many quaint villages and visited mountain resorts and historical monuments such as Boro Bodor, Soerakarta, and Djokjakarta. Each night was spent at a station hotel because there were not enough night travelers to make train operation pay and besides it was rather dangerous.

When our train returned to Batavia, I discovered that my film case was missing. I thought that it had been stolen, but the hotel manager said not to worry and he telegraphed an alarm over the entire rail system. In an hour he had an answer. When I had gone into the diner, the train stopped at Padalarang, a junction. The porter removed my film case by mistake and put it on a train bound for Buitenzorg at the end of the other line. The wire further stated that the case would be back on the next train to Batavia—and it was. The hotel man said that pilferage and robbery were rare things in Java because escaping the law was too difficult on such an island.

After leaving Java, we spent a few days in Singapore and then went on to Ceylon to visit the tea plantations. Colombo, the seaport, was uncomfortably hot, but in Kandy, 2500 feet above sea level, we found the temperatures at 75 degrees—an ideal climate. I had no trouble developing films there, and set to work immediately, for I had found out years before that film should be developed as soon as possible after exposure—especially old film. I had tested exposed film which had not been developed for two years and found it had lost the image entirely. However, if such film were re-exposed and developed

immediately, it gave a beautiful negative with no sign of the first exposure.

Rio de Janeiro in April, 1911, was delightful, but we could not tarry. The day after our arrival we were bound for Argentina and Chile. We found Buenos Aires a magnificently laid-out city, an exciting new experience. It was booming, with new streets and buildings being built everywhere. Our hotel, the Plaza, was brand new, having just opened before our arrival.

By train we crossed the great plain called La Pampa to Mendoza at the foothills of the Andes and up those rugged mountains to a resting place called the Bridge of the Incas. So thrilled were we with the awesome scenery en route that, through the co-operation of the railroad company, we did our filming from the engine's cowcatcher. This gave us an unobstructed front view, but, at the same time, the natives had an unobstructed view of us as we perched there on a sofa-like seat secured to the cowcatcher. A ludicrous sight no doubt—but we did not mind so long as we got our pictures. It was rough riding at times—in fact, the jiggling finally put my camera out of commission. But the knowledge gained in similar experiences in Java, and a good day's work with my tool kit put the camera in working order again.

We left the train at an elevation of 10,000 feet and proceeded on horseback to the great statue of the Christus, over 13,000 feet up in the bleak, snow-covered pass.

We found Valparaiso partially in ruins from an earthquake similar to the one that devastated San Francisco five years before. Santiago offered a number of good camera subjects and a hotel which proved excellent as a place to develop the films taken so far. I kept at it so late one night that I had to miss dinner. But a handy fruit stand supplied me with the most delicious pears I have ever eaten. Some of them were cactus pears. The climate in that region is very much like Southern California, but California never gave me pears so tasty.

Our return over the trans-Andine railroad occurred in a midwinter snow. That line was abandoned a few years later because of the difficulty in keeping it open and the costly repairs resulting from the rough going through the passes. Today, people cross by plane several hundred miles to the south over a beautiful lake region, not snow-clad mountains.

In Buenos Aires we heard of the great Iguassu Falls, an eleven days' journey north up the Rio de la Plata and the Alto Parana. The

river steamer took us to within thirteen miles of the falls; the rest of the way was traveled by wagon over a road cut through the jungle. Because of the rapid growth of plants and trees, the road had to be cleared every two weeks to keep it open.

The difficulty of reaching the falls was forgotten when we beheld them—the most beautiful series of cataracts in the world. And to have the opportunity of being the first to photograph them successfully made the trip even more worth while. We carefully filmed each group of falls—the colorful, inspiring Brazilian group, the Argentine, the Three Musketeers, and the Union, which drops 220 feet in one great plunge. We remained there nearly a week and slept on crude bunks in a barn with only the rats to keep us company. But we had the constant roar of the falls to lull us to sleep—an even better sleep-producer than lapping waves or rippling brooks.

When we returned to Rio de Janeiro, we chose the hotel Corcovado, up 2300 feet where the temperature was ideal for developing. Well do I remember standing on the site where now the great statue of Christ is located. I photographed a sunset and far below, the lights of the city and of the great seaside boulevards as they twinkled on at dusk. While I was turning a slow series and not making any noise, suddenly a wild fox leaped out on the sheer slanting rock not over twenty feet in front of me. As soon as he saw me, he turned carefully and fled. I say carefully because one misstep would have meant a fall of one hundred feet or more.

Time will not permit me to tell of other foreign journeys to the Orient and European lands and in our own United States. The tour of the Philippines in 1913 was one of the high spots in our careers.

I must touch briefly, however, on our association with the Paramount Company for whom we had contracted to produce weekly releases of our tours from 1908 to 1922. This resulted in six years of unbroken weekly travelog releases in Paramount Theaters.

And so I come to the end of my first fifty years of motion picture work, stretching back through the years to 1893 when Burton Holmes and I first met. But the final chapter is still in the making—for we both are still going strong. He is carrying on his lectures and packing the houses all over the country, and I am busy every day, turning out Depue printers. Surely we two have been fortunate in having the opportunity to "grow up" with the motion picture industry and to choose phases of it in which we were intensely interested. Certainly we "got what we wanted"

A SURVEY OF THE APPLICATION OF PHOTOGRAPHY IN NAVAL RESEARCH, TESTING, AND DEVELOPMENT*

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Summary.—*The Chief of Naval Photography recently conducted a survey to determine to what extent the various bureaus and offices of the Navy utilize photography to record, supplement, and document the information and findings of test, research, and development projects. This paper is a summary of that survey. Reports received indicate that motion picture photography is a* primary *tool in Naval research and testing procedures, and the methods and techniques by which photographic equipment and principles are adapted to the test problems are as many and as varied as the projects themselves.*

EARLY APPLICATIONS

Eighty-five years ago, Matthew Brady, the great Civil War photographer, stood on the deck of the Federal ironclad *Monitor* and exposed a photographic plate, a plate which was to become one of the first "photographic records" in the ever-expanding files of Naval Photography.

Brady took this historic picture following the battle in which the *Monitor* fought the Confederate ironclad *Merrimac* in Hampton Roads, in March, 1862. It is primarily a photograph of part of the ship's crew, some waving at the cameraman (possibly the ancestors of present-day "lens hounds"), others standing around their deck guns, tired, weary, and although triumphant, slightly in awe of the man with the "box" and dark cloth.

Brady exposed his plate to record the crew and the victorious ship. What Brady did not realize was this: his picture presents an accurate record of the damage done to the *Monitor* by the *Merrimac.* At least five indentations in the Monitor turret, caused by cannon balls, were recorded as proof of the strength of armor plate then in use.

It is significant that photography in the Navy, for the next eighty years, was confined almost exclusively to the pictorial: United States Forces landing in Samoa in 1892, the first liberty party in Yokohama in 1907, street fighting in Vera Cruz in 1914 during the Mexican Border trouble, and pictures of damaged ships during the first World War.

Still picture files of the Navy, during these early years, present a true and fairly complete record of events. These pictures, however,

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were taken for historical value, for public information release, and for recruiting purposes. The day of technical photography was yet to come.

Motion pictures were in use, to some degree, during the first World War, but have been lost to history. A disastrous flood in 1925 inundated a film warehouse in Washington, D. C., resulting in the total loss of the Navy's motion picture files.

To a ship's cook must go much of the credit for bringing technical photography into prominence in the Navy. He was the late Walter L. Richardson, affectionately referred to as the "Grand-daddy of Naval Photography".

During the 20's when, as up to that period, the major portion of photography of Naval subjects was performed by civilian photographers, Richardson decided that he could print a picture better than bake a pan of rolls, and after much persuasion he received consent from his commanding officer to build himself a photo laboratory at Pensacola, Florida, the present site of the Navy's School of Photography. His photo laboratory consisted of a darkroom which was set up in a combination broom closet and sink. Brooms, mops, and pails disappeared and photographic prints appeared, prints which were to be sanctioned officially by the powers that be, prints that finally broke down objections and led the way to the day when Richardson wangled his way into a two-seater plane and photographed fleet target practice from the air. His camera was homemade, his lens was purchased by a protesting supply officer, but his flight made Naval photographic history. High-ranking Navy officials were just as pleased with results of the first aerial photography then, as they are today with results of the trimetrogon cameras.

The Navy eventually instituted a school at Pensacola to train photographer's mates and Richardson was the instructor. Photographers were rated enlisted men, but photography was still in the pictorial stage. The pictorial print, plus occasional progress shots, filled the requirements. At that time, exposure meters were laughed at by Navy photographers. Although the Navy was constantly engaged in research, testing, and developmental work, the tie-in with the photography was lacking. There were a few photographers, however, who realized that the camera could do more than record a parade, the exchange of command, or the spectacular shot of a battleship firing salvos.

One of these enlisted photographers is now a Lieutenant and in charge of the Navy's photographic research and development section. He had read of the new "black-light" or infrared-ray plates but was

unable to convince his supply officer that these new plates had a place in Navy photography. Hoping to use infrared photography to help guide ships in heavy fog he purchased plates with his own money. Filters were unobtainable so melted coal tar was spread between two sheets of glass. Following much experimentation, a six-hour exposure produced an acceptable picture. His dream for infrared photography, however, was fruitless. Many years later, radar and its attendant scope photography, finally solved the problem.

Technical photography, prior to World War II, was almost nonexistent. Monopack color film was used in motion picture cameras to record the splashes of dye-filled shells used in fleet forced firing, and black-and-white motion picture film was used to record landings of aircraft aboard carriers. Certain other photographic procedures were employed, it is true, in still classified subjects, but the true extent of photography as applied to testing and research had not been realized.

WARTIME APPLICATIONS

The change in utilization came about with the advent of World War II, during which time Navy photographic activity increased almost a thousandfold, from the more obvious uses before 1940 to the present application of film and paper to projects involving pictures of shock waves, exhaust gases, and the effect of underwater explosions on submarine hulls.

Credit for the fullest application of the photographic processes as employed in testing, research, and development must be given to the many civilian engineers, who either suddenly volunteered to fight in uniform, or who sprang to their country's need in the many laboratories under Navy control.

Photography, and especially Navy photography, came into its own, awaking suddenly to find that a combination of emulsion and print paper could contribute as much toward winning the war as the 16-inch shells of our biggest battleships.

The standard motion picture cameras, the still cameras, and the new cameras in the minds of inventors were to become potent weapons in the hands of skilled cameramen and technicians. Photography accepted the challenge of new weapons, new processes, new procedures, and secret research. For the Navy, a new type of photography had emerged.

The Navy is proud of its program which has resulted in the standardization of equipment, materials, and processes for normal use.

However, standardization gave way to improvisation with the new emphasis on the application and utilization of the photographic processes to provide means of recording data in the many varied types of testing, research, and development projects.

Whereas the basic principles of the types of photography which are commonly applied to testing and research projects remain somewhat constant, the methods and procedures by which these principles are adapted to the problem at hand are as many and varied as the problems themselves. These methods and procedures must often be devised and formulated for entirely new types of testing situations and developmental projects which require unused and untried ideas in the realm of photographic techniques.

A previously untried idea that worked, for example, was the removal of the lens from a Sonne strip camera, to record certain phenomena occurring at Bikini during the atom bomb tests.

Does the reader of a national publication, on seeing a feature story on underwater photography, illustrated by full color pictures, realize that his enjoyment of that article can be traced to previous experiments in underwater photography? The Bureau of Ships found it necessary to photograph damage to submarine hulls as much as 700 feet under water, at the moment of explosive impact. This requirement led to the invention and application of special cameras and films for this underwater research.

The Navy's Bureau of Yards and Docks, worried about stress analyses, was able after extensive application to develop a new procedure for recording this stress by the photoelastic principle. This was accomplished by using both motion picture and still photography adapted with the aid of a polaroscope projector and mercury-vapor-arc illumination.

Following years of testing and research, the Naval Observatory now makes its time determinations photographically with comparative ease. The observatory time signals are based on astronomical observations made with the photographic zenith tube, a telescope permanently mounted in a vertical position. The images of the stars crossing the meridian near the zenith are impressed on a moving photographic plate 45 mm square as small dots, while the exact instants at which the plate reaches certain specified positions are recorded on a chronograph. The photographs are subjected to precise measurement under a microscope. This observation, the most accurate method known of determining time, is also used for investigating

the variation of latitude resulting from the motion of the pole. Great strides have been made in solar photography. Daily photographs are made of the sun for the purpose of recording sunspots, whose prevalence is related to magnetic interference with radio and telegraphic communication.

The research, development, and testing of many items of ordnance equipment have been greatly expedited by the use of specialized applications of photography to determine yaw and deformation; X-ray photography to determine imperfections, correct assemblies, arming characteristics, and deformation of recovered samples.

Development and test of bombs and projectiles require a very wide variation of photographic application including the use of two specially designed cameras; one to record oscilloscope traces for measurement of peak and change of pressure recorded by a piezoelectric gauge subjected to both underwater and air blasts, and the other to measure velocity of detonations of high explosives. Underwater, X-ray, high-speed, and spark photography are also used on these projects.

Motion picture color photography is used by the same Bureau (1) to photograph tests of smoke munitions for color comparisons and persistence; (2) to make studies of the development of flashes; and (3) to study the volume and color of gun-muzzle smoke formation.

The Bureau of Ordnance has found a special use for the high-speed motion picture cameras developed during the war. Burst patterns of projectiles and rockets, fragmentation, wave actions from underwater explosions, velocity of detonation, and impact patterns have all been caught with the camera's eye for evaluation at leisure.

With the advent of guided missiles, the motion picture camera has contributed immeasurably by providing triangulation and instrumentation recording.

While the rocket often escapes human vision, high-speed motion pictures permit study of a rocket at all points in its trajectory, including determination of altitude, acceleration, velocity, yaw, pitch, and roll.

Photography is the mainstay in the guided-missile research burner laboratory where various fuel mixtures and combustion-chamber designs are tested. Color motion pictures record the conditions of the tailpipe and the appearance of the exhaust stream as to intensity, color, shock, and waves. Readings of indicator gauges on test stands of rocket and jet engines, recorded photographically, may later be plotted against time or against each other in analyses which represent indisputable chronology.

The Navy has also applied Schlieren, shadowgraph and interferometric photography in testing, research, and development. Sonic and supersonic testing employs optical methods to assist in the evaluation of flow characteristics. Each of several methods used employs a transparent test section and depends upon the variation of refractive index of the flow medium with density. As a beam of light passes through the test section, interference fringes are recorded by cameras. The optical methods are particularly useful because optical apparatus does not interfere with flow.

The Electrical Section of the Bureau of Ships has applied high-speed photography to its research program on shock. Ships have been made safer and personnel have been protected to a greater degree through the results of tests showing behavior of various elements of equipment at the instant of shock impacts. Such pictures have recorded displacements and other items leading to failure of equipment caused by sudden shock or prolonged vibration.

Improved minesweeping gear has resulted from photographic research by the same Bureau when the configuration of types of minesweeping gear, as streamed from a minesweeper, has been studied.

The field of radar and television photography has intrigued photographers since the appearance of the scopes. This type of photography has, by now, few limitations. No discussion will be made of the varied uses of scope photography, other than to describe a recent development of the Navy wherein a television or radar scope can be photographed on 35-mm film, and viewed, either directly through the film within a minute, or in the form of 8- by 10-inch paper enlargements within little more than several minutes. The recording and viewing process is continuous, thus providing a strip record of subjects previously seen on the scope.

The Bureau of Medicine and Surgery has pioneered certain types of still and motion picture photography in color. Surgical techniques and medical procedures developed during the war are now permanent records for posterity and for instructional purposes in medical schools and institutions outside the service. Crash-impact movies, photographed at more than 1000 frames a second, in color, have aided in the development of more practical safety harnesses for aviators. Color, in this case, was used primarily because muscle conformation, skin reaction, and blood distribution could be more easily observed at the moment of crash impact upon volunteers.

The Bureau of Medicine and Surgery is also actively interested in

radiography, photofluorography, the X-ray microscope, spectroscopy, radiometry, infrared, and ultraviolet photography.

Every bureau and office of the Navy Department carries on tests which require the application of cameras to record instrument readings. Many of these readings occur too rapidly for the human eye to follow, and frequently the test requires that the readings of several instruments be known before accurate evaluation can be made. This one application of photography—which was a radical idea before World War II—is now a commonplace procedure and accepted as standard practice. Seldom does a plane go aloft on a test hop, for instance, without having cameras installed to record every detail of the flight as shown by the reactions of the instruments.

Such a summary as this paper attempts to present necessarily must omit any discussion of photography which is being employed in conjunction with projects of a classified nature. It can be assumed rightly, however, that photographic processes are utilized to the fullest extent in these projects.

An oft unheralded by-product of photography in the research, testing, and developmental fields has been the valuable film footage used as a basis for the 5020 Navy training films produced since that fateful seventh of December, 1941. Unproduced would have been such films as "The Effects of Aerial Bombs", "Deep Water Diving", "Operation of Electronic Equipment in Aircraft", and "Operation of Mechanical Time Fuzes".

This report of the Navy's application of photography to research, test, and development projects has shown how this particular aspect of photography was recognized and put to work during the late war. The acceptance of this photographic tool has been so widespread throughout all Naval activities that the Navy now finds itself in the position of requiring developments in new equipment and procedures to carry out its expanding program of photographic utilization. (Appendix A lists some of the most important of these requirements.)

No greater testimony could be made to the acceptance of the camera as a scientific instrument by the Navy than the success of the photographic operations conducted jointly with the Army to record the atom bomb blasts at Bikini. The behavior of the greatest phenomenon of our generation has been recorded on photographic film and paper so that scientists, engineers, technologists, and other experts may have accurate test data at their disposal in evaluating the results of these experiments.

APPENDIX A

Realizing that photographic techniques are playing an important role in the Navy's research program, the Office of Naval Research gathered information from all Naval activities pertaining to present applications of photography and future requirements. The following list contains the most outstanding items of photographic research in which the Navy is interested. These requirements were published so that industrial and academic institutions may keep in mind the interests of the Navy in planning their research and development program.

A. Photographic Chemistry

1. Film bases which have no dimensional change.
2. Fine-grain silver-halide emulsions.
3. Fine-grain emulsions, not silver halide.
4. Color emulsions.
5. A combination developer and fixer.
6. Dry development.
7. Improved equipment and techniques for night photography.
8. A lens formula computer.

B. Still Photography

1. Smaller combat cameras with built-in exposure meters.
2. Simplified camera mechanisms.
3. A camera for series photographs of operative techniques.
4. A measurement-recording camera.
5. Stroboscopic still and stereoscopic motion picture and still cameras.

C. Motion Pictures

1. A combat, portable (sound) 16-mm camera.
2. Standard sound apertures for all motion picture cameras.
3. Development of direct focusing finder through the taking lens, similar to the Cine Flex camera.
4. For use with oscilloscopes, a variable-speed motion picture camera that will take single frames with automatic action.
5. A compact single-unit projector combining the functions of two projectors.
6. A sterile, mobile, universal camera stand for use in surgery.

D. Emulsions, Black and White

1. A film with minimum expansion or shrinkage, with maximum mechanical strength, noninflammable, and with a minimum or no deterioration due to aging or tropical conditions.
2. Plastic emulsions and film bases.
3. Glass plates with rigid emulsions for astrometric and physical observations.
4. A higher sensitivity for film, both for motion picture work and for photography in regions outside the visible spectrum.
5. High-speed molecular grain emulsions.
6. A film with high contrast and high speed, for tracer photography of missiles.
7. Selective filtering and sensitivity characteristics at various wavelengths for camouflage detection, water-depth determinations, and fluorescent scope photography.
8. Accurate chemical mixing with chemical stability.
9. In microphotography, a continuous paper printing machine with maximum width for rapid processing of enlargements from microfilms; and a nonshrinkable transluscent base for an enlarging emulsion to be used to produce, from microfilm, enlarged reproductions suitable for preparing blueprints.
10. As applied to storing film, the final image after long storage periods should show a minimum loss in quality or mechanical strength, accomplished by:
    (*a*) Treatment of original images.
    (*b*) Special storage of original images.
    (*c*) Special duplication to an intermediate image having better keeping characteristics, preparation of more stable photographic materials.
    (*d*) Use of safety stock to eliminate fire hazards.

E. Color Emulsions

1. Improved natural color.
2. Photomicrographs of microscopic structure of metals and other materials.
3. Increased color sensitivity, increased speed.
4. Nondiffusing color components.
5. Uniform spectral photographic response.
6. Single emulsion sensitive to both daylight and artificial light.
7. Reproduction and enlargement of microfilm to color prints.

8. Simplicity of color processing, with uniformity.
9. Three-dimensional color, negatives, and prints, with and without use of optical viewing devices.

F. Photography in Regions Beyond the Visible Spectrum

1. High-speed X-ray movies; high-voltage X-ray motion pictures and stills.
2. Screens for photofluorography, with increased output upon exposure to all types of radiation, particularly X-ray, alpha, beta, or gamma rays, electrons, neutrons, etc.
3. Increased brilliance of X-ray fluorescent screen at least tenfold, resulting in lowering X-ray exposure time and use of a lens of lower value.
4. Visualization of invisible radiations, such as X rays by reproduction upon a television screen.
5. In radiometry, increased sensitivity to X rays, gamma rays, alpha and beta particles, neutrons.

G. Specialized Photographic Techniques

1. Improved underwater cameras with negative of sufficient size to be enlarged without loss of detail.
2. Better lighting facilities, and underwater television, as a locating device for underwater photography.
3. Television for mapping and intelligence, in color (compact, for use in forward areas).
4. Three-dimensional television.
5. A quantitative photographic record of radiation emitted by vapors of material under test, and a means of measuring spectrograms produced.
6. Cinetheodolites, with long-focus lens and radar-directed telephoto motion picture cameras with high magnification and narrow field lenses for tracking missiles at great ranges, possibly using infrared.
7. A traversing camera for subsonic speeds covering 25,000 feet of path with a missile speed of 300 to 400 miles per hour, taking 10 pictures a second.
8. Traversing camera for supersonic speeds, taking pictures of a 20,000-yard path and at 2100 feet per seond. Must be a system of cinetheodolites capable of locating missile with minimum accuracy of $^1/_{40}$ of a second in time and 1 mil in angular

measurement from which range, trajectory, velocity, acceleration, and aspect can be determined.

9. Timing devices with actuating shutters or light sources at proper instant in relation to detonation. Accuracy to a fraction of a millisecond.
10. Aerial cameras with gyrostabilized mounts and true vertical indicators.
11. Photocell exposure control using a high-sensitivity photoelectric-cell meter with $^{1}/_{1000}$ foot-candle sensitivity without fatigue or drift in values.
12. Photography of moving photoelastic models or full-scale mechanisms.
13. A technique for recording in color, self-luminescent objects in a darkroom. Color rendition from emitting object itself, not external light.

H. High-Speed Photography

1. Multilens or other type cameras recording at rates of 100,000 feet per second or faster with one-microsecond exposure time per frame.
2. A full frame 35-mm variable-speed camera capable of making 100 to 5000 exposures per second.
3. Single-frame, single-sweep photographs of oscillograms on standard 35-mm camera.
4. High-speed shutters; between-the-lens type, with minimum inertia and a minimum of $^{1}/_{1000}$ of a second exposure, operated by other than mechanical means.

I. Microtechniques

1. Solving problems of discontinuity of surface and coarse grain of emulsion, rapid reproduction, and visualization in reading machine.
2. Photographic material to microfilm in color and enlarge color microfilm to print in color.
3. Rotary-type camera capable of accommodating engineering drawings up to 40 inches in width and of indefinite length. Use 35- or 70-mm film and have variable reduction ratios. Automatic feeder for use with 3- $\times$ 5-inch and $8^{1}/_{2}$- $\times$ 11-inch documents.
4. Reader, size of drafting table, with self-contained screen at top

and with variable magnification so that microfilmed image may be enlarged and viewed at its original size. Magnification should be automatically controlled with stops provided at 17, 24, and 29 diameters.

5. Examination and record of small parts, chemicals, soundtrack detail, etc. Camera with stable support and optics capable of 10 to 1500 diameters magnification.

J. Lenses

1. Refinements in optics; development of new optical materials should be applied to lens design to increase the speed and efficiency.
2. Precision mounting of lens and means of precisely varying the location of the photosensitized material.
3. Wider-angle coverage for motion picture camera lenses and individual aerial camera lenses.
4. Optical device to aim camera successively in two or more directions.
5. Development of longer-focus lenses with highest possible resolution, hermetically sealed and thermally stabilized.
6. Improved lenses for night photography.
7. Improvements in zoom lenses for special effects in aerial or regular still and motion picture photography.
8. Improved, flat-field, high resolving-power lens for microphotography.
9. A lens-formula computer.

K. Light Sources

1. Further developments in spark, stroboscopic, and polarized light.
2. Cold light for projector lamps and for illuminating source for surgical photography.
3 For underwater photography:
   (*a*) Sufficient illumination to light an object at ten feet in slightly turbid water.
   (*b*) Light in selected wavelength, particularly from the red portion of the spectrum.
   (*c*) Repetitive flashes to eliminate raising camera to the surface after each exposure.
4. High-intensity flash bombs for night reconnaissance using both visible and infrared light.

CALLIER Q OF VARIOUS MOTION PICTURE EMULSIONS*†

J. G. STREIFFERT**

Summary.—*A physical transmission meter was built in which both the diffuse and the specular transmission of a film sample could be measured successively at the same point on the film. Q factors computed from these data are plotted as functions of the diffuse density. No base nor minimum density correction is made and hence the computed Q factors are effective rather than absolute values. A few examples are given showing the result of making such base density corrections. Data are given on a wide range of both picture and sound negative and positive materials. In each case, phototubes and filters were selected to simulate the effective range of spectral light used in the practical usage of the material.*

INTRODUCTION

Almost every use to which photographic materials are put involves the measurement of photographic density. In the motion picture industry the establishment and maintenance of uniformly high picture and sound quality depend on precise density determinations for the control of exposure and gamma.

Such determinations are usually made on instruments which measure "visual diffuse density", since the conditions for this type of measurement can be specified and realized quite easily, and such measurements have proved quite adequate for control purposes. However, the conditions which must be fulfilled for visual diffuse measurements of photographic materials are almost never those met in practical use, and therefore, although the user may know quite precisely what the visual diffuse density of a given area of a photographic material is, he seldom, if ever, knows what density that area presents when the material is put to actual use.

All this implies, and this was first shown by Callier, that density depends on the method of measurement, or on the method of use, of the photographic material. This is because a photographic deposit scatters light as well as absorbs it, and hence the density which the material appears to have depends on the efficiency with which the scattered light as well as the specularly transmitted light is collected and integrated. If all the scattered or diffused light, as well as the specularly transmitted light, is collected and integrated, a *diffuse*

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† Communication No. 1146.

** Kodak Research Laboratories, Rochester 4, N. Y.

density measurement is obtained, whereas, if none of the scattered light but only the specularly transmitted light is measured, a *specular* density measurement is obtained. In any given application of a photographic material, the *effective* density lies somewhere between these diffuse and specular values, depending on the efficiency with which the diffused light is collected or used. For example, in the case of contact printing, the effective density of the negative is very nearly the same as the diffuse density, while in the case of projection systems, the effective density has a semispecular value.

Obviously, it would be quite impracticable to attempt to make density measurements on a material in all the ways and on all the equipment on which that material might be used. Measurements of diffuse and specular densities would, however, indicate the range of densities within which the effective density must fall. Usually the results of such specular and diffuse density measurements are presented in the form of curves relating the ratio of specular to diffuse density, which Callier called Q.

The measurement of diffuse density is readily accomplished by using a light-integrating sphere to collect and integrate all the light escaping from the film and measuring this integrated light either visually or photoelectrically. True specular density measurements are not so easily obtained, however, since such measurements require perfect collimation of the light incident on the film and measurement only of those emergent rays which are parallel to the incident rays. This requirement puts severe limitations on the source of illumination and on the aperture of the optical systems on both sides of the film. If, however, the angles of illumination and of collection are held to a few degrees, a close approximation to true specular density can be attained. Clearly, the specularity in this case is far better than would obtain in any ordinary use of a photographic material.

Density determinations also depend to some degree on the quality of light used and the color sensitivity of the light-sensitive device. Thus, while most densitometers measure *visual* diffuse density, usually implying tungsten illumination and the normal human eye or an equivalent phototube and filter as a light-measuring means, such visual densities cannot be assumed to be those which obtain when a different illuminant, such as ultraviolet light, or a different light-sensitive device, such as blue-sensitive positive film or an infrared-sensitive phototube, is used.

The data which follow were taken to determine the magnitude of

the quotient Q for various motion picture emulsions, and how that ratio depended on diffuse density, on the spectral quality of the light, and on the gamma or degree of development.

APPARATUS

Preliminary tests soon indicated that it was impossible to obtain consistent and accurate values of Q if the diffuse and specular density measurements were made on different instruments, since it was impossible to be certain that the same area was being measured in the two

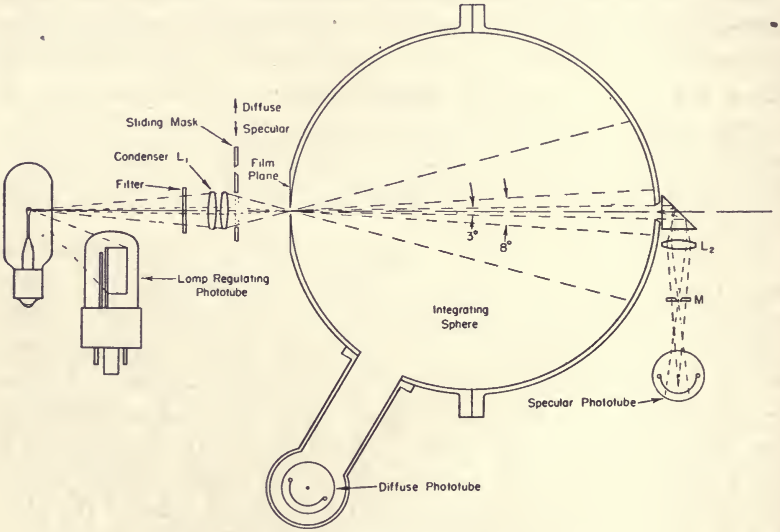

FIG. 1. Optical system of transmission meter.

cases. To overcome this difficulty, a special optical system was set up which permitted measurement of both diffuse and specular transmission without moving the sample. A schematic drawing of this optical system is shown in Fig. 1. As indicated by the diagram, the lamp filament is imaged on the film at the entrance to the integrating sphere by means of a high-aperture condenser lens L_1. A sliding mask near this lens has two openings in it—one of which permits light from the entire lens to pass for diffuse measurements, while the other limits the angle of illumination of the film to approximately 8 degrees for specular measurements. A phototube near the bottom of the sphere samples the integrated light in the sphere. A small hole in the back of the sphere opposite the entrance aperture permits those

light rays within a solid angle of 3 degrees to escape. After reflection by the prism, a lens L_2 forms an image of the illuminated area of the film in the mask M. By this means, diffuse light from the wall of the sphere adjacent to the entrance aperture is prevented from falling on the phototube which measures specular transmission. This same lens L_2 also forms an image of the hole in the back of the sphere on the phototube. A switch attached to the sliding mask at the condenser lens selects the diffuse or specular phototube, depending on whether lens L_1 is open or restricted in aperture.

Fig. 2 shows the electrical circuit used in connection with the phototubes. Since the phototube load resistors were of the order of 10 megohms, some trouble was experienced from leakage and dark current. When reasonable precautions failed to reduce these currents to a satisfactorily low value, a small bias battery and potentiometer

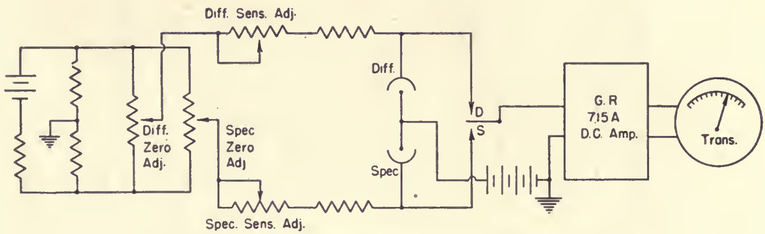

FIG. 2. Phototube and amplifier circuit.

arrangement were introduced to cancel their effect. Thus, by means of the two "zero adjust" potentiometers, the transmission meter could be made to read "zero" for either phototube when it was dark, and by means of the "sensitivity controls", the meter could be made to read "100 per cent" for either phototube with no sample in the beam. It was thereby possible to make diffuse and specular transmission readings in quick succession without changing the position of the sample. The indicating instrument was a Weston Model 1 milliammeter which permitted transmission to be estimated to ± 0.1 per cent of full-scale deflection. A multiplying factor of 10X in the amplifier allowed transmission measurements as low as 0.1 per cent to be made, corresponding to a density of 3.0.

The light output from the lamp was stabilized by means of an auxiliary phototube and electronic control circuit which were capable of maintaining the intensity constant to ± 0.25 per cent for a line-voltage

variation of 90 to 130 volts. The lamp used was an 8.5-volt, 4-ampere exciter lamp, normally operated at about 3.75 amperes.

Diffuse density readings on this instrument were found to check very closely the readings of integrating polarization photometer and integrating photoelectric instruments. Although the collimation of the light used in the specular measurement admittedly is not perfect, it is far better than would obtain in ordinary use of a photographic material.

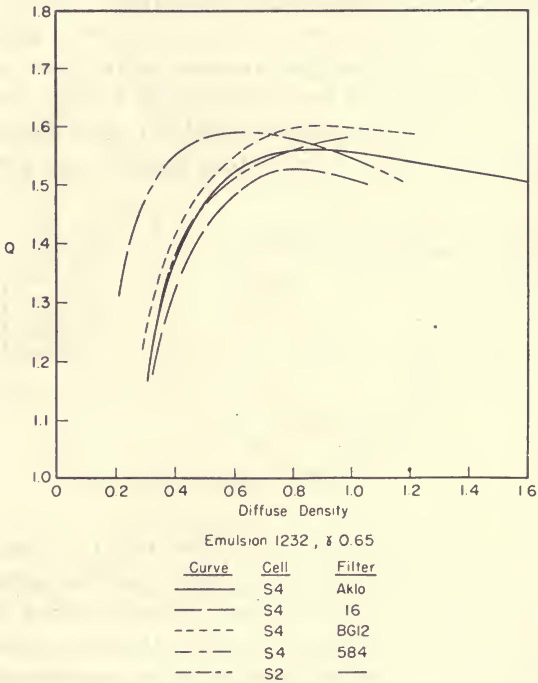

FIG. 3. Callier Q vs. diffuse density for Eastman Super-XX Panchromatic Negative Film, Type 1232, using various filter and phototube combinations.

Density samples of various films for measurement on this instrument were prepared by gradually increasing the exposure on a flashing machine so that a density wedge 50 to 100 feet long was obtained. It was soon found that in order to obtain true and consistent results, particularly at low densities, it was necessary to take every precaution against accumulation of sludge or spots on the film during processing, as well as against dirt and scratches during handling and measurement.

RESULTS

Q versus Light Quality

In Figs. 3 through 7 are shown curves relating Q to diffuse density for several common motion picture materials and for several qualities of effective radiation. These curves are not corrected for the minimum base density owing to reflection or absorption of base dyes, and hence these values of Q must be considered as effective values rather than absolute values for the photographic deposit itself. Such base

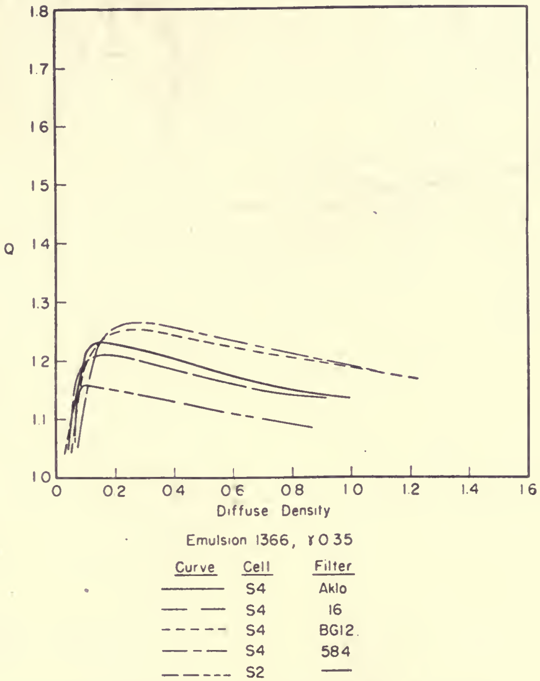

FIG. 4. Callier Q vs. diffuse density for Eastman Sound Recording Film, Type 1366, using various filter and phototube combinations.

densities account for the fact that the minimum diffuse density in the case of Type 1232, for example, was as high as 0.3.

The various filters and phototubes used placed the peak of the band of radiation used in the measurements at various wavelengths ranging from approximately 380 to 800 millimicrons. In Fig. 3 for Eastman Super-XX Panchromatic Negative Film, Type 1232, the curves for various spectral regions are fairly well grouped, indicating only a slight

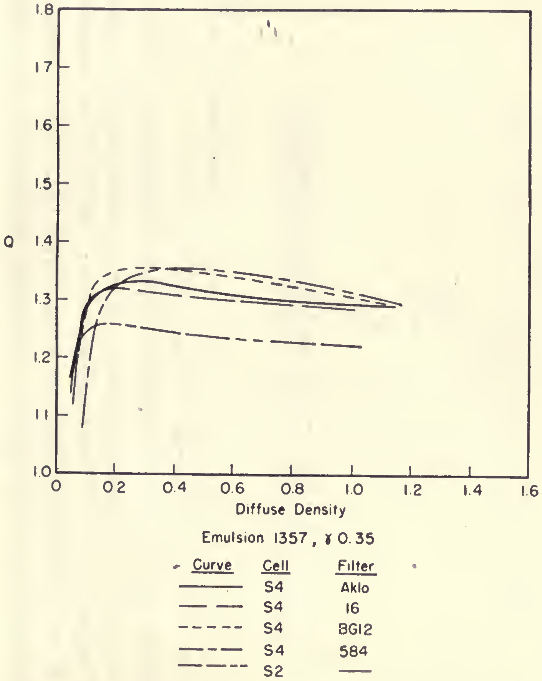

FIG. 5. Callier Q vs. diffuse density for Eastman Sound Recording Film, Type 1357, using various filter and phototube combinations.

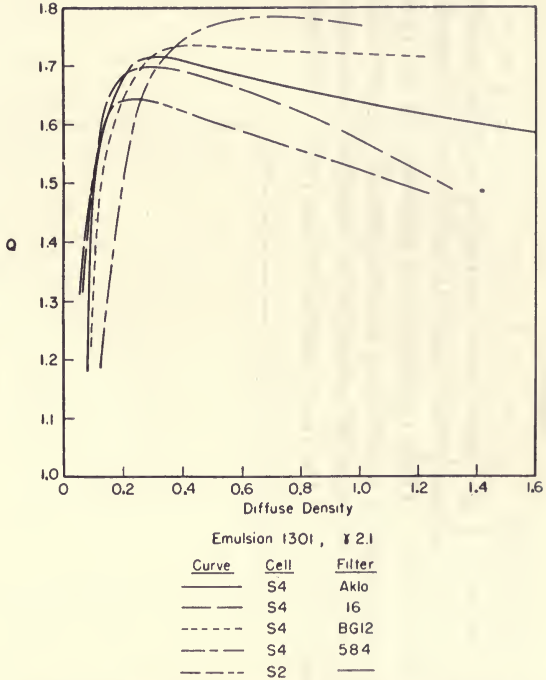

FIG. 6. Callier Q vs. diffuse density for Eastman Release Positive Film, Type 1301, using various filter and phototube combinations.

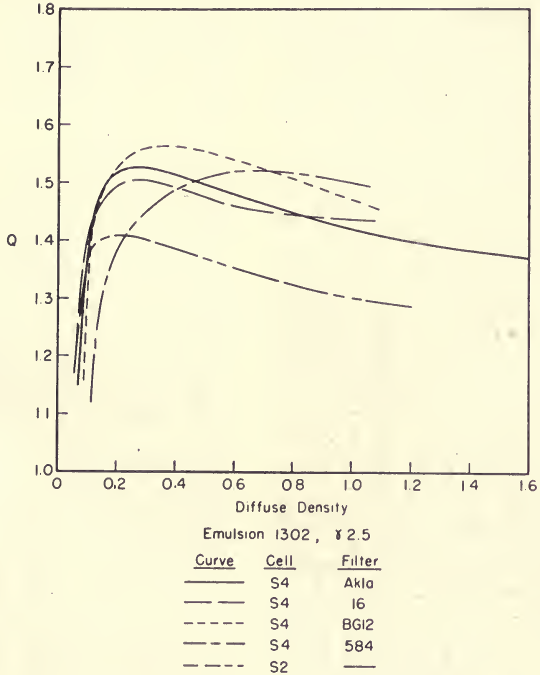

FIG. 7. Callier Q vs. diffuse density for Eastman Fine Grain Release Positive Film, Type 1302, using various filter and phototube combinations.

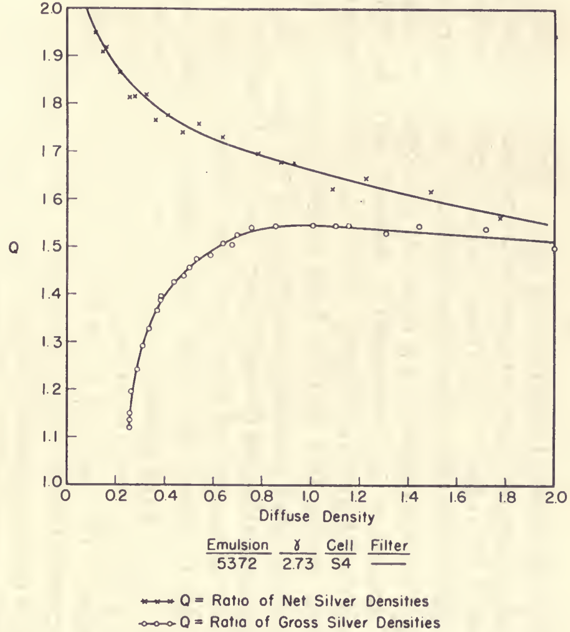

FIG. 8. Callier Q vs. diffuse density for Eastman Fine Grain Sound Recording Film, Type 5372.

dependence on the spectral quality of the light. The shift to the left in the case of the infrared curve is caused by the reduced absorption of the gray base in this region. Fig. 4 gives similar data on Type 1366, a fine-grain variable-density negative material used some years ago. At all except very low densities, it is seen that Q is lowest for infrared light and increases as the wavelength is reduced, until the highest value is reached with ultraviolet light. This is, as would be expected, because of the known fact that the light-scattering property of an emulsion increases with decreasing wavelength of the light. The fine grain of this material results in much lower values of Q than for Type 1232. As will be brought out later, these lower values of Q for Type 1366 may also be due in part to the lower gamma to which it was developed. Fig. 5 gives similar data on Eastman Sound Recording Film, Type 1357, at about the same gamma as the Type 1366 of the previous figure. The values of Q are higher than for Type 1366, as would be expected, because of the coarser grain of this material.

Fig. 6 gives data on Eastman Release Positive Film, Type 1301, at a normal print gamma of 2.1. Substantially higher values of Q are indicated here. Curves on Eastman Fine Grain Release Positive, Type 1302, at a gamma of 2.5 are shown in Fig. 7. The effect of the finer grain of this material is again apparent. A direct result of the lower Q of Type 1302 as compared to that of Type 1301 has been experienced throughout the industry in the need for higher gamma development of Type 1302 prints than for Type 1301 prints. The reason for this is that the H and D characteristic curve, based on diffuse densities, must be corrected, point by point, by multiplying the diffuse densities by appropriate values of Q. By this means a value of what may be called "projection gamma" is obtained. Clearly, if this projection gamma is to be the same for both emulsions, Types 1301 and 1302, and Type 1301 has a higher Q than Type 1302, the control or diffuse gamma of Type 1302 will have to be higher than that of Type 1301.

A typical curve on Eastman Fine Grain Sound Recording Film, Type 5372, is shown in Fig. 8. The lower curve showing the effective Q again shows the effect of the gray base on curve shape. The upper curve of this figure shows the effect of replotting the data after the minimum specular and diffuse base density have been subtracted from the gross specular and diffuse readings, respectively. To arrive at this minimum base density, samples of unexposed stock were fixed, washed, and dried, and the diffuse and specular densities were

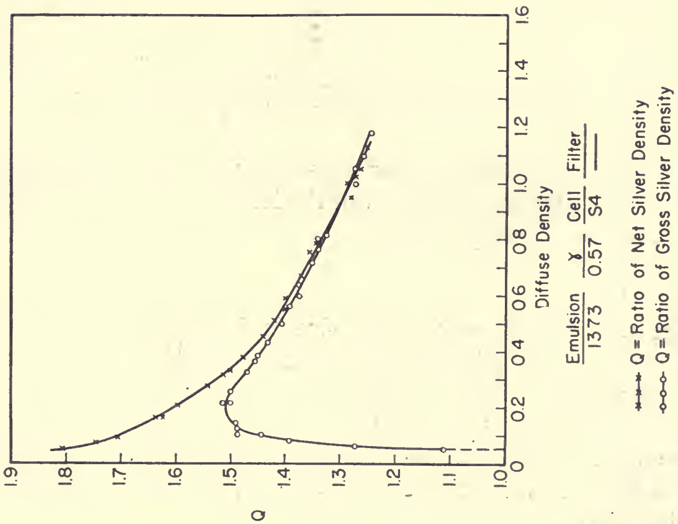

FIG. 9. Callier Q vs. diffuse density for Eastman Sound Recording Film, Type 1373.

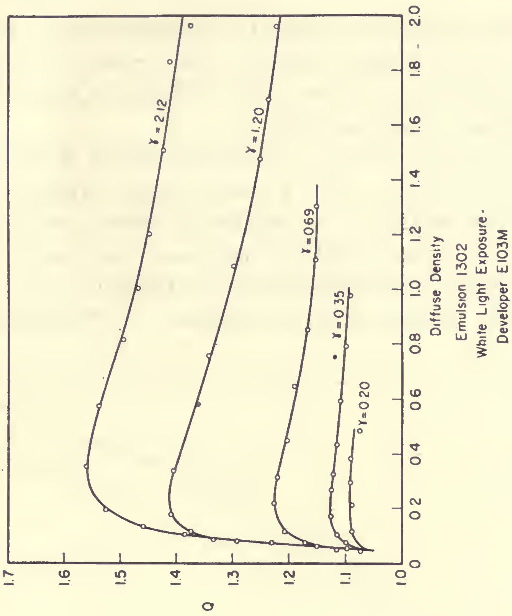

FIG. 10. Callier Q vs. diffuse density for various gammas. Eastman Fine Grain Release Positive Film, Type 1302.

measured. This upper curve is thus the relation of the Q of the silver deposit itself to its diffuse density. The curve rises sharply at low densities, indicating a higher ratio of diffusion to absorptior at low densities than at high densities.

Fig. 9 shows similar curves on Eastman Sound Recording Film, Type 1373. These curves show a rather large variation of Q with density. The continual decrease of Q with density, as indicated by the curves which are corrected for minimum base densities in this figure and in Fig. 8, is probably explained principally by the fact that the most sensitive grains, which are exposed by low light levels and

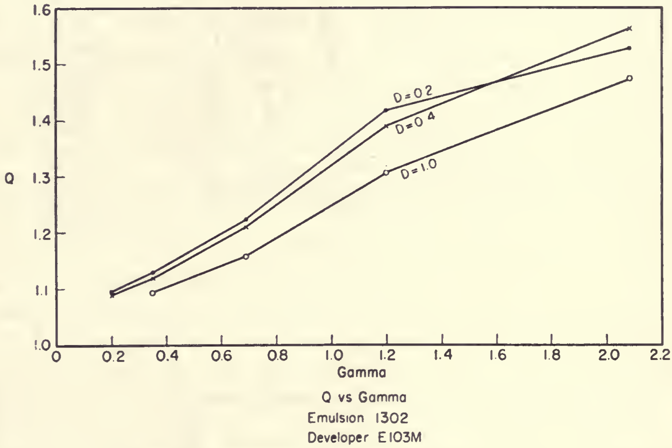

FIG. 11. Callier Q vs. gamma for various diffuse densities. Eastman Fine Grain Release Positive Film, Type 1302.

which therefore contribute to low densities, are larger and therefore produce more scattering of light than the less sensitive smaller grains which contribute to high densities.

Q versus Gamma

By the same token, since grain size is dependent on degree of development, one would expect Q to depend on degree of development, that is, on gamma. Fig. 10 shows curves of Type 1302 at various gammas. From these same data, curves can be plotted between Q and gamma for various values of diffuse density. Such curves are shown in Fig. 11 and indicate an almost linear relationship in this particular case.

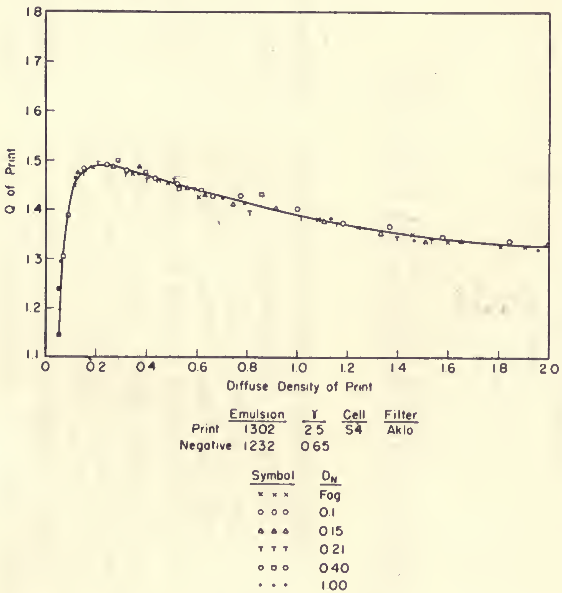

FIG. 12. Callier Q of Type 1302 print of Type 1232 negatives of various densities vs. diffuse density of print.

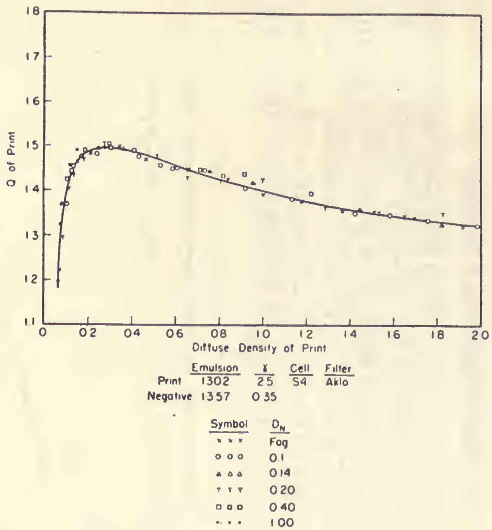

FIG. 13. Callier Q of Type 1302 print of Type 1357. Negatives of various densities vs. diffuse density of print.

Q of Print versus Negative Material and Density

In order to determine whether the Q of a print material was in any way influenced by the method of exposure or by the Q of a negative material, contact prints were made from a variety of negative materials, and at each of a series of negative densities. The results for prints made on Type 1302 of Type 1232 negatives of various densities are shown in Fig. 12, indicating no dependence of the Q of the print

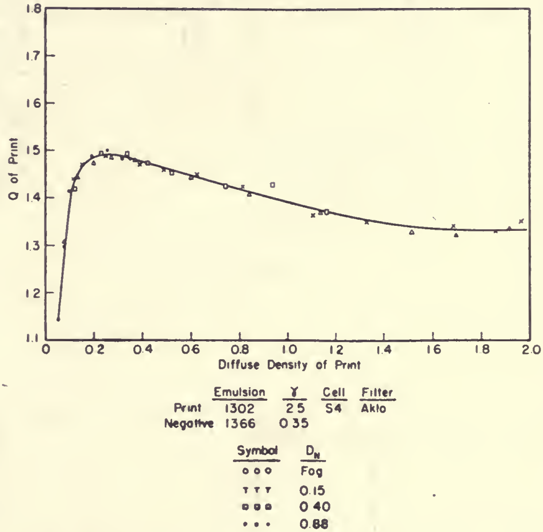

FIG. 14. Callier Q of Type 1302 print of Type 1366 negatives of various densities vs. diffuse density of print.

material on the density of the negative. This is in fact the same curve that was obtained for Type 1302 when exposed on the flashing machine. Similar curves for Type 1302 prints of negatives made on Types 1357 and 1366 are shown in Figs. 13 and 14, respectively.

In Fig. 15 are shown data on neutral Kodachrome dye images and on the sulfide sound-track image. As is well known, the dye image absorbs but does not scatter the light; hence, the low Q in this case. The apparent upturn of the curve for the dye image at low densities is probably caused by surface dirt, scratches, and so forth, since these strips were subjected to considerably more handling before

measurement than were the black-and-white samples. The curves for the sulfide sound-track image indicate that the light-scattering property of the silver-sulfide particles is comparable to that of a silver deposit in a fine-grain positive material. The shape of these curves is greatly influenced by the high minimum density, which is due to stain.

As was pointed out earlier, in but few practical applications of photographic materials do the effective densities approach either the strictly diffuse or strictly specular values. An exception is the case of contact printing where the effective density of the negative is very nearly the same as that measured with a physical diffuse densitometer

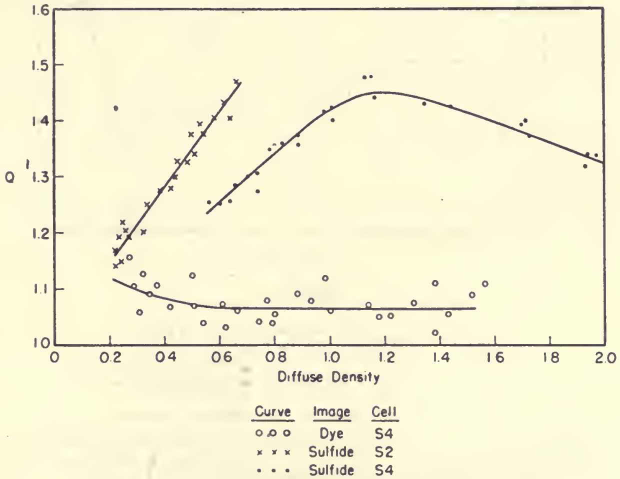

FIG. 15. Callier Q of Kodachrome dye and sulfide images.

using light of the same quality as would be effective in exposing the print material. In all cases of projection printing, picture projection, and sound reproduction, the effective density depends on the relative apertures of the condenser and objective optical systems. To illustrate this, in Fig. 16 two curves are plotted, the top one being the relation between diffuse density and the ratio of the specular to diffuse density values, and the lower one being the relation between the diffuse density and the ratio of the effective density, as measured by a commonly used sound-reproducer optical system and phototube arrangement, to the diffuse density. Optical systems in which the

phototube is very close to the film would show values of Q somewhat lower than this curve, whereas the "inverted" type of reproducing system would show higher values.

The dependence of effective density on the particular optical system being used can be illustrated in another way. Fig. 17A shows curves relating intermodulation to diffuse density for several reproducer optical systems. These systems included a typical push-pull optical system as used on commercial projection equipment; a laboratory

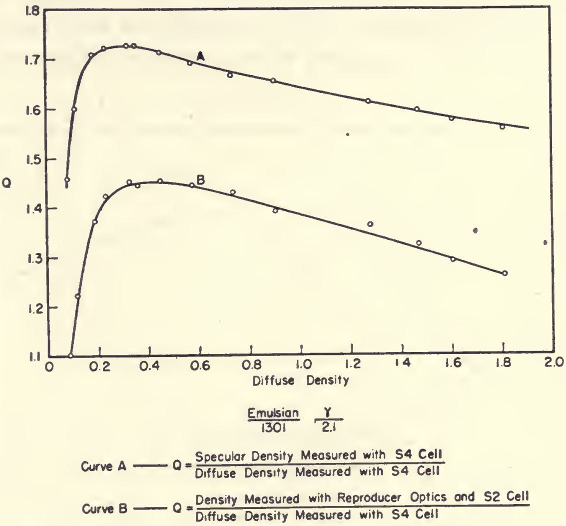

FIG. 16. Ratio of specular to diffuse density vs. diffuse density. Curve *A:* Specular density measured on transmission meter; Curve *B:* Specular density measured with typical sound-reproducer optical system.

film phonograph with slit-type optical system and phototube arrangement but no collector lens; the same system with a collector lens as close to the film as possible and with a 0.17-inch diameter mask over this collector lens; and last, the same arrangement but without the mask. It is obvious that a print of a given diffuse density can give optimum performance on only one of these optical systems. In other words, the correct diffuse print density must be determined on the basis of the particular optical system with which the film is to be used. If these same intermodulation data are plotted against effective densities as measured by the same optical systems as were used in obtaining the intermodulation data, a single curve results, as shown in

Fig. 17B. This suggests that many of the differences between intermodulation data as measured by different laboratories might be eliminated if the density in each case were measured on a physical densitometer in which the optical system was a duplicate of that used in the reproducer.

CONCLUSION

It must be emphasized that (1) *density* has true significance only in terms of the instrument or equipment upon which the photographic material is used and (2) the ratio of specular, or effective density, as

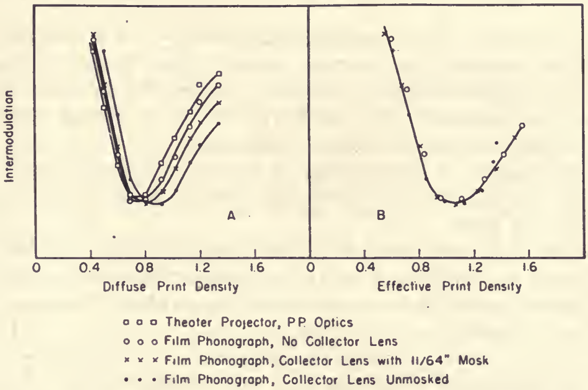

FIG. 17. Intermodulation vs. density for various sound-reproducer optical systems.

the case may be, to diffuse density, depends not only on the optics involved, but also on the emulsion, on the developer and gamma to which the image was developed, on the value of the diffuse density, and to a degree on the spectral quality of the effective light. There is probably nothing particularly new about these concepts. However, it is hoped that the foregoing data have served to throw some new light on the nature of these relationships, to illustrate their magnitude, and to re-emphasize the continued need for caution against confusing the ordinary diffuse density measurement with the effective density in any particular application.

ACKNOWLEDGMENT

The author wishes to give credit and sincere thanks to Dr. O. Sandvik for his guidance and many helpful suggestions, to Mr. J.

Munushian and Mr. J. Green for their assistance in making measurements and plotting data, and to Mr. W. Grimwood for the intermodulation data.

DISCUSSION

DR. J. G. FRAYNE: Is there any correlation between the various values of Callier Q and ground noise in sound tracts?

MR. J. G. STREIFFERT: Callier Q is obviously related to grain size, and grain size is dependent upon the degree of development and the type of emulsion. Ground noise also depends on grain size.

DR. FRAYNE: Have you made any actual experiments to obtain any data?

MR. STREIFFERT: No, we have not made any correlation between those factors.

DR. OTTO SANDVIK: If one measures the Callier Q of a material which has received a direct exposure (not printed), there is a fairly good correlation between the value of Q and ground noise. However, the granular structure of a print depends largely on the negative from which it was made, and ground noise from this print depends on the granularity of the negative. As shown in the paper, the value of Callier Q is independent of the material from which the print is made. It is evident that the correlation between ground noise and Callier Q would not be very good.

DR. FRAYNE: It would seem, in view of this information that the percentage intermodulation is a function of the type of optics, that there ought to be some sort of movement initiated by some association, perhaps this one, to standardize sound optics in motion picture reproducers.

DR. SANDVIK: I think that is an excellent idea. It would be well to standardize the optical systems since data show that optimum print density as determined by intermodulation tests is dependent on the type of reproducer optical system used.

DR. E. W. KELLOGG: RCA, I believe, has had an M-2 system since we began building reproducers. However we did not standardize it.

THE SENSITIVITY OF VARIOUS PHOTOTUBES AS A FUNCTION OF THE COLOR TEMPERATURE OF THE LIGHT SOURCE

A. CRAMWINCKEL*

Summary.—*A description is given of a measuring method and measurements for ascertaining the sensitivity of different types of phototubes, viz., cesium-oxide, gas-filled, and vacuum phototubes, cesium-antimony vacuum phototubes, and selenium photovoltaic cells, as a function of the temperature of the light source (tungsten ribbon lamp). The results are compared with the surface brightness of the light source as a function of the temperature.*

INTRODUCTION

When judging the usefulness of an incandescent electric lamp, e. g., for projection purposes, attention first will be paid to the surface brightness which the lamp shows to the eye, expressed in candle power per square centimeter, this quantity increasing in a well-known manner with increasing temperature of the filament. This evidently will give no difficulties because the brightness of the screen in projecting is appreciated by the human eye itself.

From figures in candle power per square centimeter of the surface brightness it is possible without further comments to make an estimate of the increase in efficiency with increasing temperature.

A different problem occurs when we wish to estimate the efficiency of a light source used for scanning a sound track by means of a phototube. It is not to be expected that the increase of the phototube current (proportional to the incident light flux, provided the light has a *constant* spectral energy distribution) will correspond with increasing temperature of the filament to the increase of surface brightness of the filament, because the brightness is related to the spectral sensitivity characteristic of the eye (relative luminosity curve), whereas the spectral response of various types of phototubes deviates more or less from this eye characteristic.

For the estimation intended here it will therefore be necessary to know the increase of the phototube current with increasing temperature of the filament of the light source for every type of phototube considered.

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As these data were not to be found in the literature it was thought worth while to measure this increase in a number of cases. It is true that the spectral response curves of various types of phototubes are sufficiently well known and that, therefore, the function required may be computed from the known spectral distribution of the source by graphical integration, but this is a cumbersome process, which would take more time than a simple measurement.

METHOD OF MEASUREMENT

The measurements were carried out making use of a tungsten ribbon lamp, the temperature of its filament as a function of the current being accurately known. The phototube was placed in front of the lamp in such a way that the light of the filament could not reach the tube via selectively reflecting surfaces, but only either directly or by reflection against pure white or gray surfaces used for screening the phototube from other light sources. The distance between the lamp and the phototube could be varied in order that a large range of temperatures could be covered in a simple way.

First the phototube current was measured at low temperatures and at a short distance, until the maximum deflection of the galvanometer was reached. After this the distance between the lamp and the phototube was increased, keeping the current through the filament constant, until the phototube current was reduced to a reasonable value. Then measurements were carried out at higher temperatures, after which the distance was increased in the same way as before. In this way a curve for the relative phototube current as a function of temperature was obtained, consisting of separate parts, which could be linked up by simple calculation.

Finally it was only needed to check the sensitivity of the phototube for a known quantity of light (measured in lumens) at one temperature in order to be able to compare the curve obtained with those measured for other phototubes. This was always done at a color temperature of 2600 degrees Kelvin, because it is common practice to give the sensitivity of a phototube in microamperes per lumen at that temperature.

RESULTS

Four types of phototubes were measured, viz., a cesium-antimony vacuum phototube, a selenium photovoltaic cell, a cesium-oxide gas-filled phototube and a cesium-oxide vacuum phototube. Only one

specimen of each type was measured, because deviations to an extent which would influence the results in connection with the purpose of the measurements were not to be expected.

TABLE 1

T_{true}, °K	T_{color}, °K	Cs-Sb Vacuum	Selenium	Eye	Cs_2O Gas	Cs_2O Vacuum	Energy
1700	1718	(0.25)	(0.57)	0.73	1.65	(2.37)	13.7
1800	1820	0.68	1.32	1.61	3.20	4.33	18.4
1900	1921	1.68	2.86	3.32	5.76	7.39	23.8
2000	2023	3.76	5.69	6.51	9.98	12.0	30.7
2100	2125	7.94	10.7	11.9	16.5	18.9	39.0
2200	2227	15.2	18.6	20.4	26.1	28.4	48.5
2300	2330	26.9	31.0	33.1	39.8	41.4	59.8
2400	2432	45.5	49.5	51.4	57.5	58.5	73.4
2500	2535	74.3	76.6	77.6	80.9	81.5	89.0
2564	2600	100	100	100	100	100	100
2600	2638	118	116	115	112	111	107
2700	2741	180	169	163	151	147	127
2800	2844	273	242	288	200	193	150
2900	2948	412	341	310	262	253	176
3000	(3052)	605	471	416	339	327	207
3100	(3157)	(885)	(642)	545	(435)	(415)	241
3200	(3262)	(1280)	(874)	708	(550)	(522)	280
3300	(3367)	(1820)	(1180)	911	(695)	(654)	324
3400	(3473)	(2560)	(1550)	1150	(865)	(805)	370

In Table 1 the phototube current, in per cent of the value at 2600 degrees Kelvin color temperature, is given as a function of the color temperature.

Under the heading "eye" the relative surface brightness is given in per cent of the value at 2600 degrees Kelvin and in the same way under the heading "energy" the total energy radiated by the filament. The numbers in parentheses are obtained by graphical extrapolation. In Fig. 1 the results are plotted as a function of the true temperature.

In order to be able to judge how far various types of phototubes are superior or inferior to the eye with regard to the respective values at 2600 degrees Kelvin color temperature, the same data are plotted in Fig. 2 after converting to constant surface brightness.

In this figure the color temperature is used as temperature scale since, in practice, phototubes will be used in combination with spiral filament lamps and not with ribbon lamps. Now it is known that the relation between the color temperature and the true temperature for spiral lamps will be different from that for the ribbon lamps; in fact, with a spiral filament the difference between these two temperatures will be smaller because a spiral filament is a closer approach to a black body than a ribbon filament, and, therefore, we eliminate this difference when using a color-temperature scale. In addition, for a spiral

filament the average color temperature is much easier to measure than the true temperature. It is true that in doing this we get an inaccuracy by assuming that the spectral energy distribution of the spiral

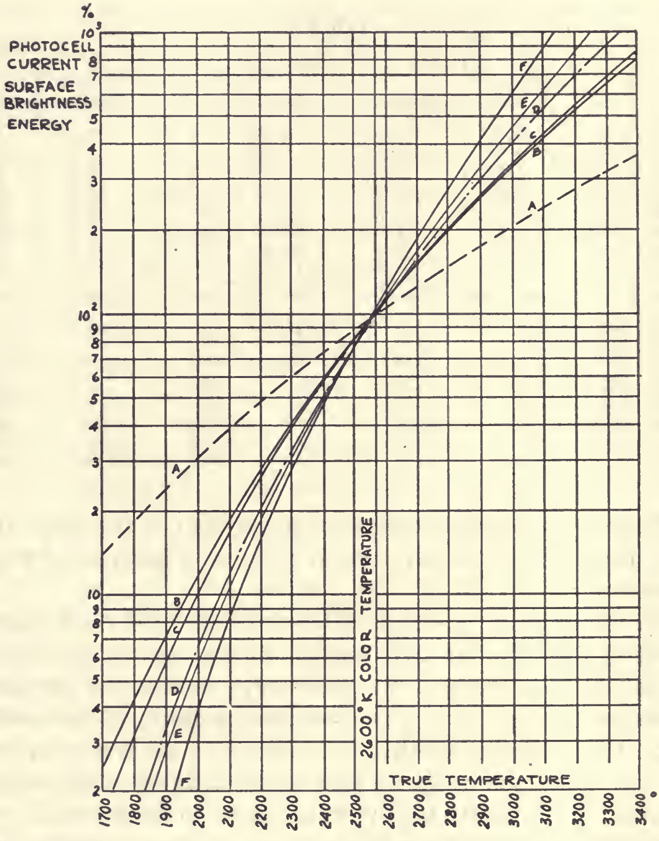

FIG. 1. The phototube current as a function of the true temperature for a tungsten ribbon lamp with different kinds of photocells. Converted with respect to 100 per cent at 264 degrees Kelvin.

A, Total radiated energy; *B*, Cs_2O vacuum phototube; *C*, Cs_2O gas phototube; *D*, surface brightness (to the eye); *E*, selenium cell; *F*, Cs-Sb vacuum phototube.

filament is equal to that of a black body both in and outside the range of visible radiations, whereas in reality this is only checked for two wavelengths in the visible range of the spectrum. This inaccuracy, however, is so small that it may as well be disregarded.

The sensitivity of the different cells in microamperes per lumen at 2600 degrees Kelvin, obtained by absolute measurement, is given in Table 2.

TABLE 2

Type	Sensitivity
Cs-Sb vacuum	36 μ a/lumen
Photovoltaic Se	390 μ a/lumen
Cs_2O gas	120 μ a/lumen
Cs_2O vacuum	41 μ a/lumen

As a selenium photovoltaic cell gives rise to a current which is proportional to the incident light only when no higher countervoltage

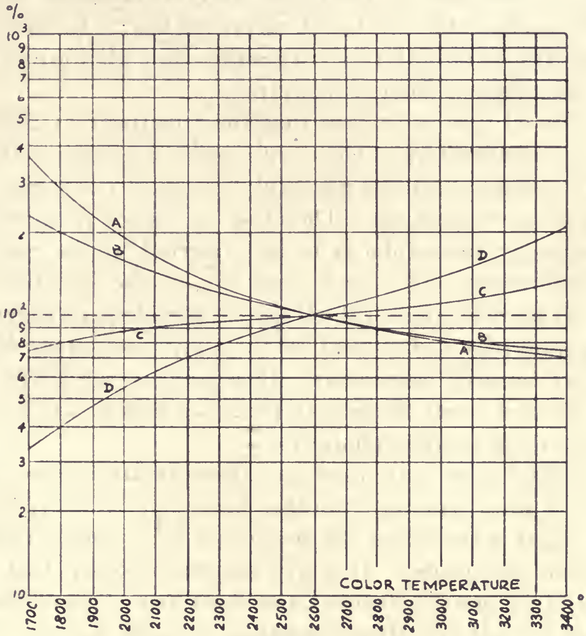

FIG. 2. The relation between the phototube-sensitivity and the eye sensitivity as a function of the color temperature for different kinds of phototubes. Converted with respect to 100 per cent at 2600 degrees Kelvin.

A, Cs_2O vacuum phototube; *B*, Cs_2O gas phototube; *C*, selenium cell; *D*, Cs-Sb vacuum phototube.

than 0.01 volt occurs in the external circuits, care was taken during measurements that this condition was always satisfied. In the nonlinear range of the characteristic it is not possible to speak of a defined sensitivity with this type of cell.

DISCUSSION

It follows from the measurements that the sensitivity of the cesium-antimony phototube increases more rapidly with increasing filament temperature than does the brightness of the filament, whereas with the cesium-oxide phototube the reverse is the case. This is because the cesium-antimony phototube is more sensitive to blue, and the cesium-oxide phototube to red, than the eye. The sensitivity of the selenium cell follows closely that of the human eye, which is to be expected, as the spectral sensitivity of this type of phototube is in rather close correspondence with the spectral sensitivity of the eye.

As the gas contained in the bulbs does not influence the spectral sensitivity of phototubes, it is not surprising that it is found that the relative sensitivity of both types of cesium-oxide phototubes is almost the same for different color temperatures.

From Table 2 it is to be seen that the sensitivity at 2600 degrees Kelvin color temperature of the cesium-oxide vacuum phototube and that of the cesium-antimony phototube is almost the same, certainly within their reproducibility. Therefore, at higher temperatures the cesium-antimony phototube is to be preferred to the cesium-oxide vacuum phototube. As is seen from Fig. 2, the sensitivity of the former is about twice that of the latter at 3000 degrees Kelvin.

The vacuum phototubes used for the above measurements proved to be rather sensitive specimens. In practice a sensitivity at 2600 degrees Kelvin of about 20 microamperes per lumen is to be expected for a cesium-oxide vacuum phototube.

The gas-filled phototube used has approximately three times the sensitivity of the vacuum phototubes measured; this type of phototube has about seven times the sensitivity of a commercial cesium-oxide vacuum phototube. It is well known, however, that contrary to the case of vacuum phototubes, the sensitivity of a gas-filled phototube under normal operating conditions strongly depends upon the voltage applied. In the neighborhood of the breakdown potential (about 150 volts) the noise of these gas-filled phototubes strongly increases, thereby reducing the signal-to-noise ratio.

The sensitivity of selenium photovoltaic cells in the linear range of the characteristic is appreciably higher than that of gas-filled phototubes, but the counter-electromotive force must be kept small (<0.01 volt) in order to ensure linearity of response, which makes their application for sound reproduction purposes less feasible, unless the phototube circuit is designed with this requirement in mind.[1]

This and other respects in which the photovoltaic cell differs from phototubes of the photoemissive type, such as impedance, frequency response, and noise characteristics, must be borne in mind before concluding that this type of photocell is the one most suited for sound reproduction on the basis of its favorable sensitivity and spectral response characteristics alone, but its possibilities should not be overlooked.

CONCLUSIONS

(1) The sensitivity of cesium-antimony and selenium phototubes, especially that of the former, increases more rapidly with increasing filament temperature than the visually observed surface brightness of the filament. The sensitivity of cesium-oxide phototubes increases with filament temperature at a slower rate than the surface brightness.

(2) Gas-filled and vacuum cesium-oxide phototubes are practically the same in this respect, as was to be expected.

(3) At 2600 degrees Kelvin color temperature (this is the temperature at which in practice the sensitivity of phototubes is given) the sensitivities of cesium-oxide and cesium-antimony vacuum phototubes are approximately the same (in our case 40 microamperes per lumen). The sensitivity of cesium-oxide gas-filled phototubes is higher (in our case 120 microamperes per lumen); that of selenium cells when operated in the linear part of their characteristic corresponding to an external counter-electromotive force <0.01 volt is much higher (400 microamperes per lumen in our case).

(4) When using light sources of high color temperature (e. g., 3000 degrees Kelvin) in combination with a phototube, for sound reproduction, the cesium-antimony phototube is at least twice as sensitive as a cesium-oxide vacuum phototube. Therefore, the former is much more suitable for this purpose.

REFERENCE

[1] RITTNER, E. S.: "Improvement of the Characteristics of Photo-voltaic and Photo-conductive Cells by Feedback Circuits", *Rev. Sci. Instr.*, 18 (Jan. 1947), p. 36.

A MICROPHONE TILTING DEVICE*

B. H. DENNEY** AND R. J. CARR**

***Summary.**—A method of tilting and controlling the tilt of the microphone during the "take" is described. The narrow vertical pattern of the unidirectional microphone makes control of the vertical angle of incidence desirable.*

The stage microphone used in the recording of sound for motion pictures is maneuvered, not only through intricate three-dimensional paths, but rotated about its own vertical axis. Following the actors through a complex scene with abrupt changes of tempo and rapid exchange of dialog between two or more characters while dodging obstructions such as chandeliers, and keeping the microphone outside the camera lens range, requires an operator of considerable skill and an unfailing microphone support or boom. Complexity is added by a system of illumination which includes several overhead lights whose rays when interrupted by the microphone or boom cast shadows in the scene. Modern sound-recording quality demands good high-frequency response from all characters with normal speaking voices and slightly attenuated high-frequency response from all characters with voices having emphasized sibilance. This requires very accurate control over the direction of the microphone "beam" or field of good high-frequency response. In the early days of sound recording the microphone was suspended by rope and pulley devices or hidden behind objects that were conveniently written into the script. Later the microphone was, still suspended by rope, pulled and pushed over the set by ropes and long poles. Soon booms of various types were built and a limited degree of movement became possible.

About 1930 there appeared the familiar old-style Mole-Richardson counterweighted boom capable of extension and retraction and movement through horizontal angles and limited vertical angles. The horizontal and vertical angle of the microphone itself was adjusted to meet average conditions throughout the scene to be recorded. Often the microphone was "beamed" straight down, and electrical equalization was used to re-establish the high-frequency balance. Later some studios provided a panning (or panoramic) movement by

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* Presented Apr. 21, 1947, at the SMPE Convention in Chicago.

** Paramount Pictures, Inc., Hollywood, Calif.

various more or less involved methods. The tilt or vertical angle of the microphone was to remain one of compromise. The more modern lightweight microphone boom retained the original features, incorporated the panning facility and had additional facilities for elevation of the boom mechanism and the operator's platform built into the mobile dolly. The tilt of the microphone was to remain one of compromise for the scene but owing to the fairly broad "beam" of the microphones used this was not considered too serious. Yet it has

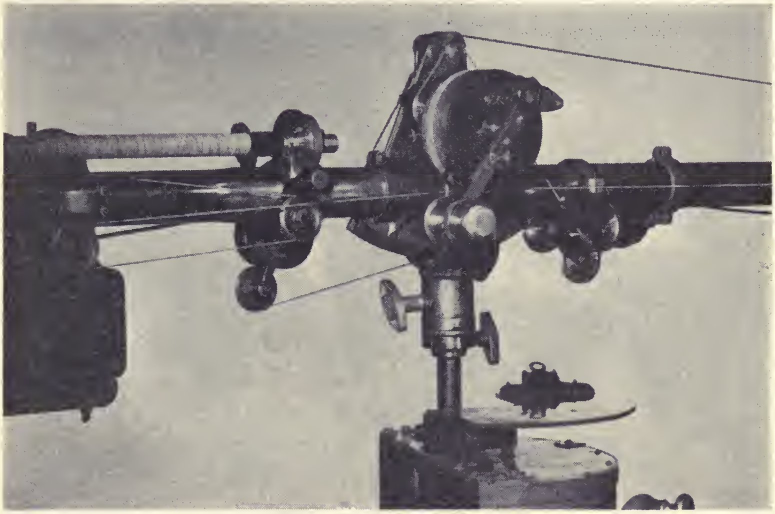

FIG. 1. Medium view of boom crank, drum, and associated apparatus.

been normal and customary to see the members of the sound-recording unit make frequent adjustments of the microphone tilt during a day's recording and in re-recording frequent electrical corrections of high-frequency response are required to compensate for the results of incorrect tilt.

The increasing use of the unidirectional type of microphone having the familiar cardioid pattern in the horizontal plane has presented the sound-recording engineer with new problems. The directional characteristic of this microphone is desirable for attenuating unwanted reverberations and off-stage noise but the advantages are partially offset by the narrow and critical high-frequency pattern in the vertical plane. Although the horizontal angle may be of optimum the best high-frequency pickup will not be possible unless the ribbon or

diaphragm is perpendicular to the sound source. In a microphone having a rectangular-shaped ribbon (or diaphragm) the high-frequency beam is widest in a plane perpendicular to the ribbon and through the short dimension. The beam is narrowest in a plane perpendicular to the ribbon and through the long dimension. To use this type of microphone efficiently a tilting device capable of operation during the scene is necessary.

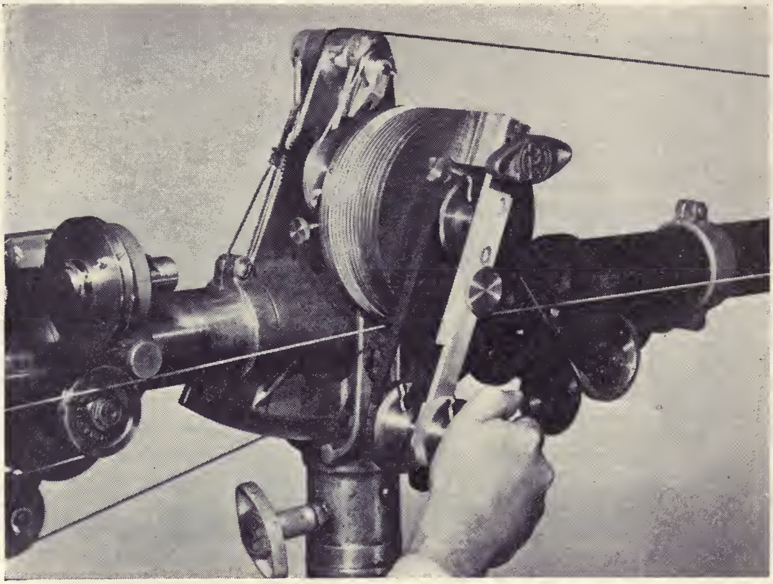

FIG. 2. Close-up of operator's hand. Crank at 7 o'clock.

The device to be described is adapted to a current model Mole-Richardson lightweight microphone boom. Several standard assembly items are used with minor changes. The major problem is that of noise both near the microphone and "telegraphed" to it through the boom arm.

Fig. 1 is a close-up view of the boom controls. The operator's left hand controls three motions. Panning is accomplished by twisting the guide bar while direct effort moves the boom through horizontal and vertical angles. The right hand normally controls one motion, the extension of the boom by means of the hand crank attached to the cable drum. The tilting control is arranged for this hand. A planetary system was devised. Fig. 2 shows the pulley on the central

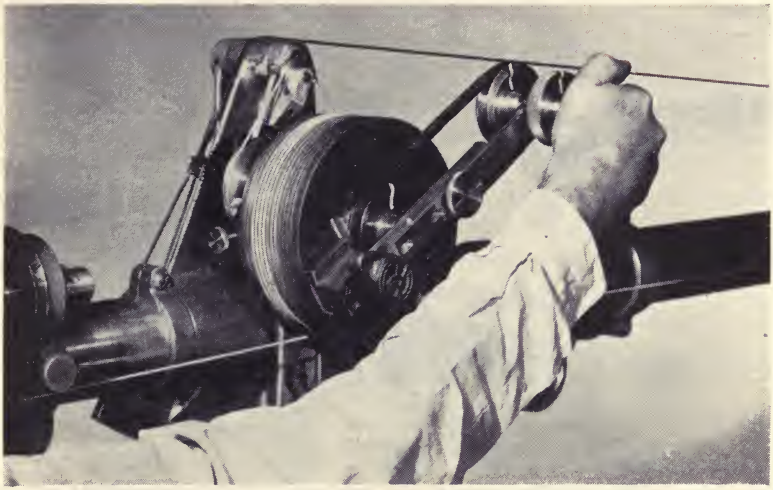

FIG. 3. Close-up of operator's hand. Crank at 2 o'clock.

shaft and the pulley on the crank-handle shaft connected by a V belt. Observe that if the central-shaft pulley is prevented from rotating, as shown in Fig. 3, the mark on the top of the crank-handle pulley remains vertical. The hand of the operator, although turning the crank, does not change in relationship to the knurled hand wheel which is connected to the crank-handle pulley. In operation the operator may extend his fingers and turn the knurled hand wheel

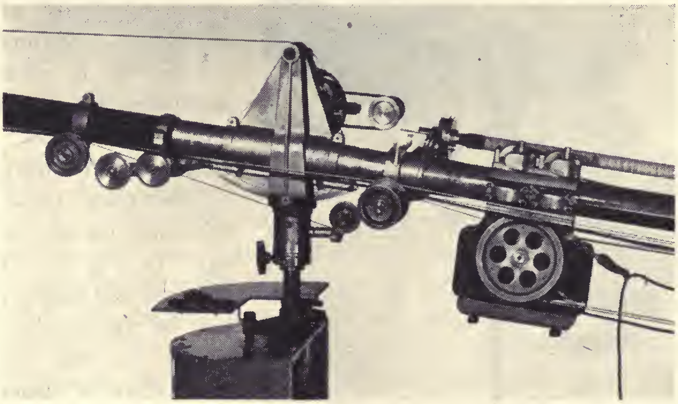

FIG. 4. Medium view of left side of boom. Tilt-control arm and sheave at 9 o'clock.

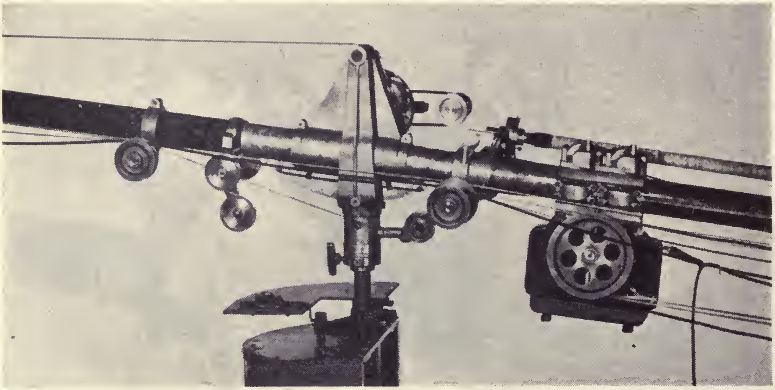

FIG. 5. Medium view of left side of boom. Tilt-control arm and sheave at 5 o'clock.

while the crank is either at rest or in motion. The center-shaft pulley connects through bakelite gears to a seine-twine drive which passes through the center line of the horizontal trunnion bearing. This prevents a change of the boom vertical angle from altering the tilt position.

The standard boom is equipped with a double-sheave system arranged with the traveling counterweight to take up the excess panning turret seine twine and the excess microphone cable. These excesses occur as the microphone-boom extension arm is retracted. A third set of sheaves is added to accommodate the twine that controls tilt. Uncompensated shortening of the seine twine tilts the microphone "beam" up. In Fig. 4, observe the arm and pulley to the left of the center support. As the knurled hand wheel is turned this arm moves downward as shown in Fig. 5.

FIG. 6. Close-up of panning turret.

The microphone tilting head is not involved. The seine twine is threaded over a series of sheaves and through the center of the panning turret, as shown in Fig. 6. Fig. 7 shows the microphone supported in a ring clamp that is suspended by elastic bands laced to an outer frame which is pivoted on a U-shaped bail. The pivot is moved forward to unbalance the microphone and hangar and to permit gravity to become the restoring force to oppose the seine twine's pull. Lord shock mountings provide a convenient, quiet, and self-aligning bearing. An arc of metal attached to the outer frame acts

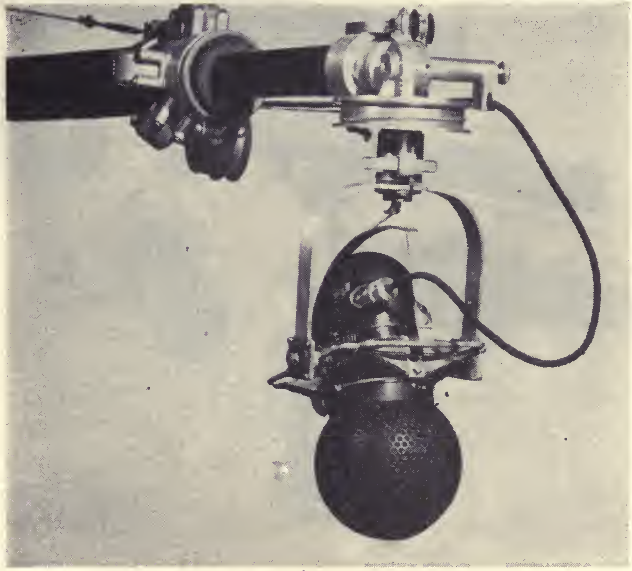

FIG. 7. Close-up of microphone in relaxed position.

as the last sheave in the twine drive. The twine threaded through the turret shaft passes over a hardened guide, the arc, and is then attached to a small windlass to take up excess twine. The U-shaped bail is threaded on the turret. As the twine is tightened the hangar and microphone move through about 100 degrees, as shown in Fig. 8.

To eliminate the necessity of threading the twine through the bail and the various length extension shafts, a $^1/_8$-inch slot is cut into the threaded insert and longitudinally through the extension shafts.

Ever since this type of microphone appeared, Loren L. Ryder, Director of Recording at Paramount Pictures, has emphasized that

for its most efficient use a tilting device capable of operation during the scene would be necessary. Under his direction the design and construction of such a device was undertaken. The convenience of the tilting microphone has been proved. It is not only possible to control the microphone through a wider range of action but in many cases to reduce the complexity of previous movements by utilization of the tilting feature.

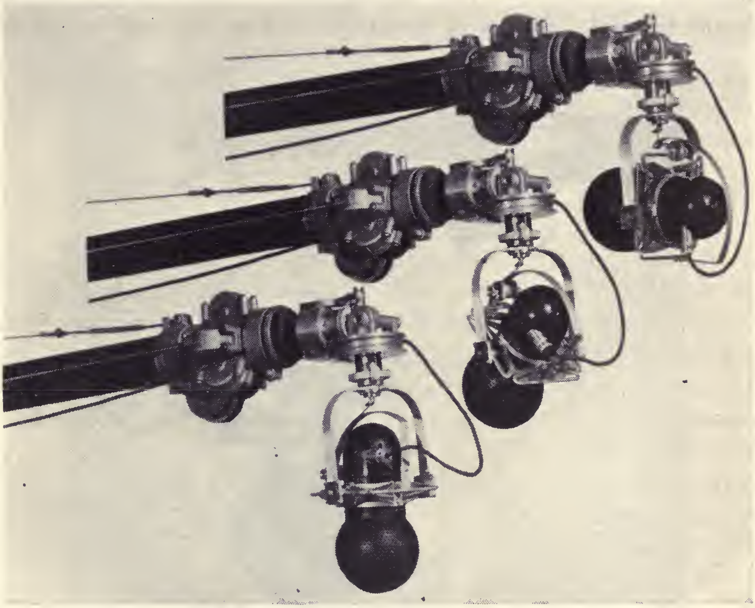

FIG. 8. Microphone in three positions of tilt.

DISCUSSION

MR. LOREN L. RYDER: This is one of those devices intended to simplify as well as aid in the shooting of motion pictures. It has been our experience that the sound pickup can be materially improved and simplified by its use. Largely it is a case of simplification because with a device of this type it is not necessary to move the boom as definitely as would formerly be the case. Thus we do not encounter so much trouble from a result of shadows and interference with lighting.

MR. J. E. AIKEN: Is that little auxiliary wheel so arranged that when the operator's hand is removed the microphone returns to its normal tilt or does it remain where he has adjusted it?

MR. RYDER: The microphone remains fixed in position unless the man actually takes hold of the knob and moves the knob to change the tilt of the microphone.

TWO MICROSCOPES FOR MEASURING THE DIMENSIONS OF 35-MM CINE FILM*

O. E. CONKLIN**

Summary.—*Two microscopes are described for plant control of the dimensions of 35-mm cine film. One microscope measures the transverse dimensions of film such as width, width pitch, and the centering of the perforations. The other microscope measures length pitch and its variations from perforation to perforation.*

In the slitting and perforating of 35-mm cine film, there are six important dimensions which must be kept within limits fixed by this Society. These dimensions are first, the length and width of the perforations themselves. Our experience indicates that the dimensions of the perforations seldom vary, and that it is sufficient to check them occasionally on a simple measuring microscope. The other dimensions are width, the centering of the perforations, the width pitch, and the length pitch.

These dimensions require constant checking. The volume of work for a motion picture raw-stock producer is such that highly specialized measuring equipment is required in order to meet the demand for both accuracy and speed of inspection. During the last twenty years we have used and discarded three different types of measuring microscopes and have recently developed and are now using two new types of microscopes, one for checking transverse dimensions and the other for checking length pitch.

The earlier methods were too slow to keep up with our volume of production. One reason for this low operating speed lay in the continued use of customary methods where each sample had to be clamped in alignment with a reference standard. With the best possible adjusting mechansims of this type the operation takes considerable time. In the new microscopes slow clamping and positioning operations are eliminated. In fact, dimensions are checked while the sample is pulled past the microscope objective.

The film holders used are designed to keep the film in accurate focus and yet allow it to be pulled in a straight line past the microscope objective. A holder consists of two metal blocks accurately ground

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* Presented Apr. 23, 1947, at the SMPE Convention in Chicago.

** E. I. du Pont de Nemours and Co., Parlin, N. J.

to form a guide slot through which the film is pulled. One edge of this guide slot is straight and fixed. Along the other edge is a flat spring which pushes the film against the fixed guide. In this way rapid and accurate film handling and positioning are secured.

Another feature may be mentioned. The film holders are drilled for a vacuum attachment which may be used to clean the samples just before they are drawn under the microscope.

The reference standards in the form of special comparison prisms are built into the optical system. The function of the prisms is to

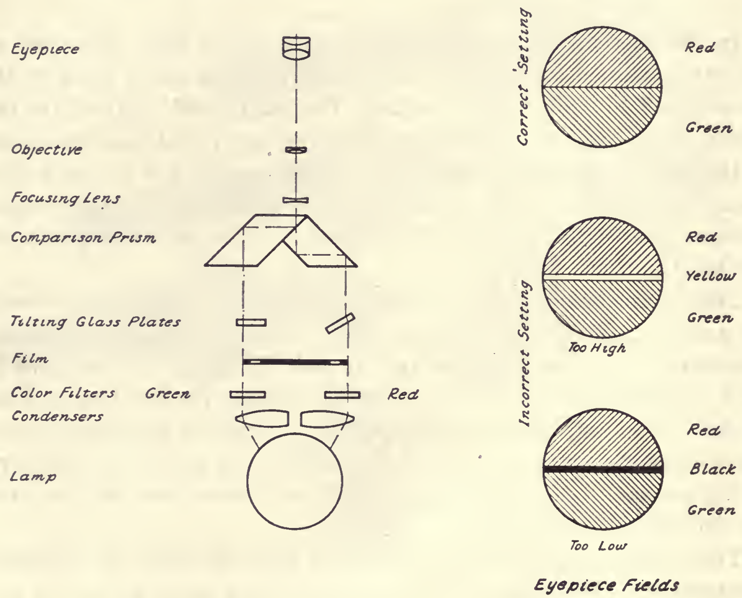


FIG. 1. Optical system for measuring width of film.

form touching or overlapping images of different parts of the film. The dimensions of these comparison prisms determine just what parts of the film shall appear to touch or overlap. Altogether four comparison prisms are needed. Three of them are used in one microscope to measure width, the centering of the perforations, and width pitch. The other is used in a separate microscope to measure the length pitch from perforation to perforation.

Fig. 1 is a sketch of the optical system which is used to measure the width of the film. The comparison prism consists of one rhomb cemented to a second truncated rhomb. At the interface is a

half-silvered mirror which both reflects and transmits light so that light beams passing the two parts of the prism join together to form overlapping images.

The prism shown in Fig. 1 is designed and constructed to make images of the opposite edges of a film of correct width touch each other. Since, of course, the width of real film varies, the two images will not always touch at the standard setting. The departure from standard is measured by a device which moves one of the images until the two just touch. This is done by tilting a glass plate which is in

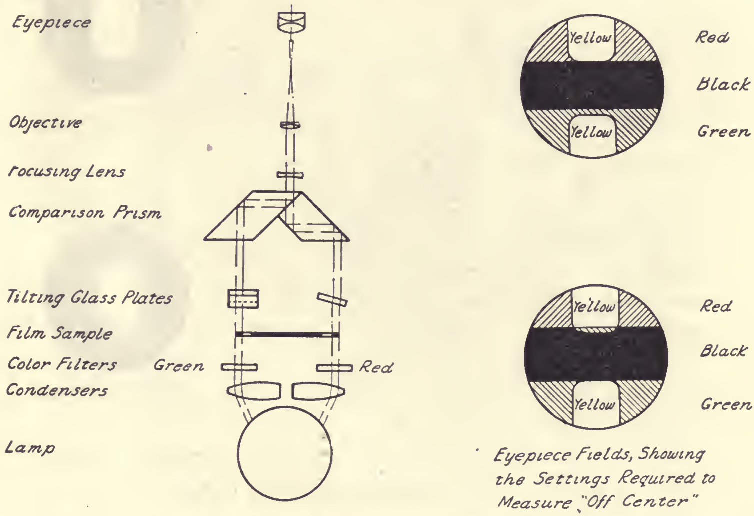


FIG. 2. Optical system for measuring centering of perforations.

the path of one of the beams. A suitably calibrated scale is attached to the plate mounting. When the two images have been made to touch, the width of the film can be read on this scale.

The combination of the film holder and this measuring system made it practicable to check the film continuously over its entire length and not at just a few scattered points.

It has been found that the accuracy of the instrument is increased by illuminating one side of the film with red light and the other side with green light. In this case the correct setting for width measurement is indicated by sharp division of the field of view into red and green parts. Incorrect settings are indicated by the appearance of either a black or yellow band between the red and green halves of the

field. The measurement of width has been described in some detail because the same principles apply to the other measurements.

Fig. 2 shows the optical system for checking the centering of the perforations. For this measurement there is a second comparison prism which forms overlapping images of the marginal spaces between the perforations and the edges of the film. Any difference in width indicates that perforations are incorrectly centered. It can be measured by use of the tilting plate, first setting the top perforation against

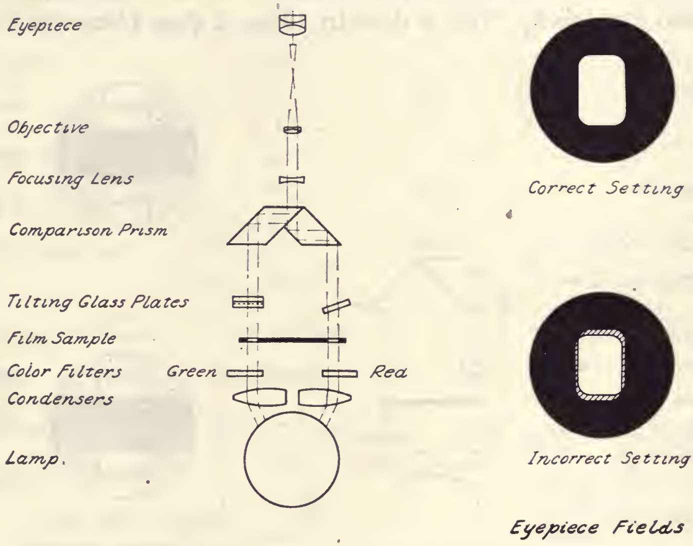


FIG. 3. Optical system for measuring width pitch.

the top edge and then setting the lower perforation against the lower edge. The difference between these settings is the off-center reading.

Fig. 3 shows the optical system for checking width pitch. In this case a third comparison prism is used to bring together images of opposite perforations. If the dimensions are perfect, only a yellow perforation is seen against a black background. Dimensional errors are indicated by the appearance of red or green fringes along the edges of the perforation. The width-pitch setting is made, using the tilting plate, by causing the color fringes to disappear at the ends of the perforations and the width pitch is read from the scale.

It has been possible to make this scale direct reading for the third and fourth decimal places of both width and width-pitch measurements by the simple device of using separate index lines for the two

measurements. The two index lines may be seen in Fig. 4, at W and P, at the side of the microscope.

Under some conditions colored fringes may be visible along the sides of the perforation. The presence of these fringes does not interfere with the width-pitch measurements. Actually an additional measurement can be made on the sample through methods similar to those described. This measurement determines whether or not the line

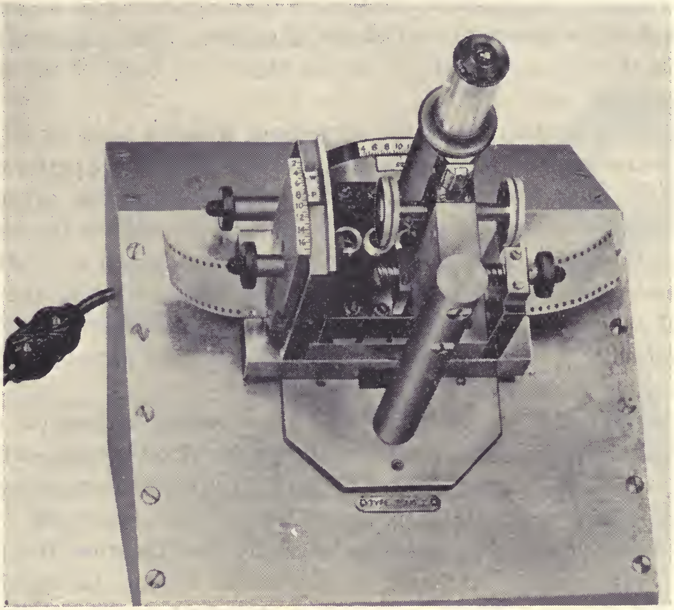


FIG. 4. Microscope for measuring width of film and other dimensions.

joining corresponding points of opposite perforations is accurately at right angles to the guided edge of the sample. To make this measurement the color fringes are eliminated along the edges of the perforations seen through the eyepiece by a tilting plate in one of the light paths. The axis of rotation of this tilting plate is at right angles to the axis of rotation of the plate used for width measurements. For mechanical convenience and symmetry, the two plates are in opposite light paths. After elimination of the color fringes as noted above, the film sample is taken out of the holder and put in a second time with its opposite face toward the observer. Thus if it had originally been in emulsion up, it is now emulsion down. When the

film sample is perfect, no color fringes will be seen after this reversal but should there be an error such that the line joining corresponding points in opposite perforations is not perpendicular to the guided edge of the film, red and green fringes will appear in this second film position though the setting had been made to eliminate them while the sample was in its first position. The tilting plate can be reset and its change of scale reading will then indicate the amount of displacement required to eliminate the fringes which in turn is a measure of the angle error commonly called out of square. The scale and index used in this measurement are shown above the body of the microscope in Fig. 4.

Fig. 4 is a photograph of the microscope which is used for all these measurements just described, width, the centering of the perforations, width pitch, and out of square. The three comparison prisms are mounted side by side in a sliding block barely visible in the picture. In an adjustable mounting over each prism is mounted a −2-diopter lens, not previously mentioned, whose purpose is to make the three optical systems parfocal with each other. After these lenses have been adjusted and locked in place, there is no need for refocusing for each shift of the prisms.

Outwardly the second new microscope, which is used to check length pitch, is very similar to the first, just described and shown in Fig. 4. Its optical system is indicated in Fig. 5. In this microscope overlapping images of longitudinally adjacent perforations are formed. Since the adjacent perforations are inconveniently close together, it is necessary to introduce a different type of prism to increase the separation of the light beams. While separated, each light beam passes through a tilting glass plate. They are brought together to form overlapping images by a comparison prism similar to that described for the first microscope. The instrument is adjusted and calibrated so that when the overlapping of the images is complete, and no color fringes are visible, the length pitch can be read directly on an appropriate scale. However, the microscope is particularly valuable in determining steadiness, that is, uniformity of length pitch. While drawing a sample of film through the microscope the operator can quickly locate any deviation from standard by watching the fringes produced and can make any needed measurements very rapidly. At the same time the operator can watch for any indication that the successive perforations do not lie in one straight line as such a defect would cause color fringes to appear at the ends of the perforation image seen in the microscope.

The reference standards in the microscopes and the scale readings are checked frequently with primary standards made of pieces of 0.005-inch spring-steel stock. These standards are made by clamping single pieces of spring steel between steel blocks with ground faces. The assembly is ground to the specified size and checked against Johannsen blocks. When disassembled we have just one primary standard, which is probably accurate to 0.00001 inch. In checking the instruments, the primary standard is placed under the microscope, a setting is made, and if necessary the index line is moved so that the reading agrees with the standard.

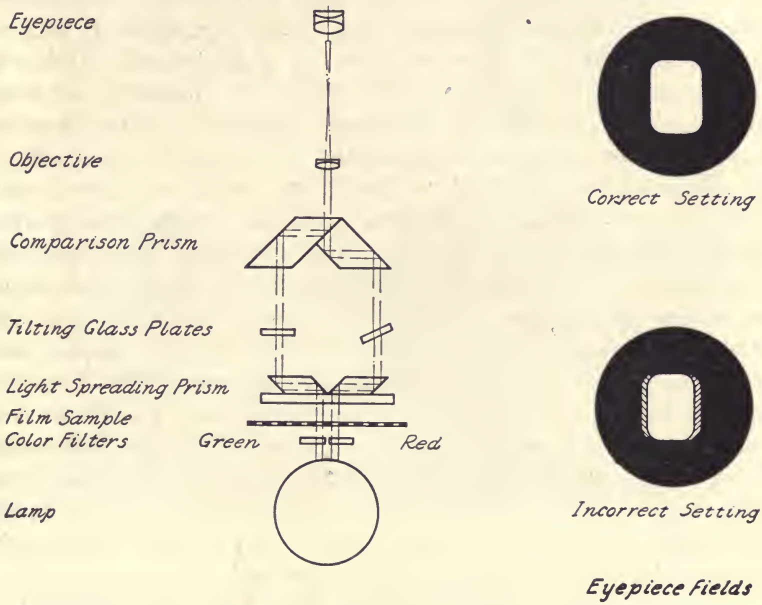


FIG. 5. Optical system for measuring length pitch.

The scale intervals can be calculated from the thickness and refractive index of the glass plates, but it is more practicable to make several primary standards of different widths in order to determine the scale intervals experimentally. Within the range used, the scale calibration is linear and can be laid out from settings on two known widths.

The effective over-all accuracy of these microscopes is about 0.0001 inch. The limiting factor is not the precision of the microscopes but the smoothness of the edges of the film and perforations.

THE MULT-EFEX TITLER DEVICE*

JAMES T. STROHM**

Summary.—*This paper describes the development and use of a new titling device which was developed for use with 16-mm and 8-mm cameras to facilitate the making of titles and special effects.*

Ever since the introduction of the 16-mm and 8-mm camera the amateur and semiprofessional cinematographer has endeavored to professionalize his films by the addition of titles and special effects. These devices were well known to the 35-mm professional cinematographer and had been used in connection with 35-mm films almost since their inception. Expensive and elaborate equipment was set up by a few firms and most of the major motion picture studios in order to make accurate titles; also, extremely elaborate and complicated optical printers were developed on which a limitless number of special effects could be accomplished. Of course, little, if any, of this equipment was available to the 16-mm and 8-mm camera user. Also, very few optical printers were developed which would permit the use of 16-mm film, and hardly any were developed for 8-mm film.

The need for such equipment for the amateur and semiprofessional has become increasingly apparent as is evidenced by the numerous articles which have appeared during the past few years in the home motion picture magazines describing the manner in which various types of homemade titlers and special-effects devices could be constructed to meet these needs. Although many of these homemade devices were extremely ingenious and capable of accomplishing some of the desired results, it was felt that there was no device or equipment which was versatile enough to satisfy all the needs which might be required by the amateur and semiprofessional.

The Bardwell and McAlister Mult-Efex Titler was designed to satisfy these requirements. A great deal of research and testing with many cameras was conducted in order to make the device extremely sturdy and simple (see Fig. 1). In effect, the device is simply a casting upon which the camera is mounted and is known as the "camera base." To this base an offset leg assembly is attached which holds a lens holder and a title platen assembly. The unit is also supplied with accessory components to facilitate the making of various types of titles and special effects, such as an auxiliary lens

* Presented Apr. 25, 1947, at the SMPE Convention in Chicago.

** Bardwell and McAlister, Inc., Hollywood, Calif.

shade, a platen shade, wipe slide, scroll plate, various cutout masks or mattes, and an auxiliary lens. The titler is extremely small and quite versatile and may be set up easily.

From past experience it has been found that regardless of what type of titling device was employed a great deal of difficulty was usually encountered, not only in aligning the camera correctly so that it would photograph the exact area of the title, but also photographing the title so that it would appear level on the screen. Because of

FIG. 1.

these difficulties the titler is supplied with an aligning device known as a "Mult-Efex Aligner" (see Fig. 2). This device is probably the most important accessory supplied with the titler and can also be supplied separately in the event other types of titling equipment are being used. It consists of a pointer and centering guide which enables the user to align the camera lens correctly with the title.

Standard 3- by 5-inch cards are employed to make normal titles with the device. The card on which the desired title is lettered, or typed, is placed on the platen assembly and is correctly aligned with the camera lens by use of the aligner described above. This aligner aligns the title in both the horizontal and vertical positions. A platen assembly bearing the title is then moved within a few inches from the

camera lens and is photographed by means of an auxiliary lens of the correct diopter, in order to reduce the focusing distance of the camera lens. Larger titles may also be made by placing them at various distances from the camera lens by employing the use of the aligning accessory to align them correctly with the camera. In such cases, of course, different diopter auxiliary lenses must be used in order to bring the title into sharp focus depending upon the distance desired. In many cases, however, when the title is far enough away from the camera the use of an auxiliary lens is not necessary and the camera lens itself may be used to focus the title or subject properly.

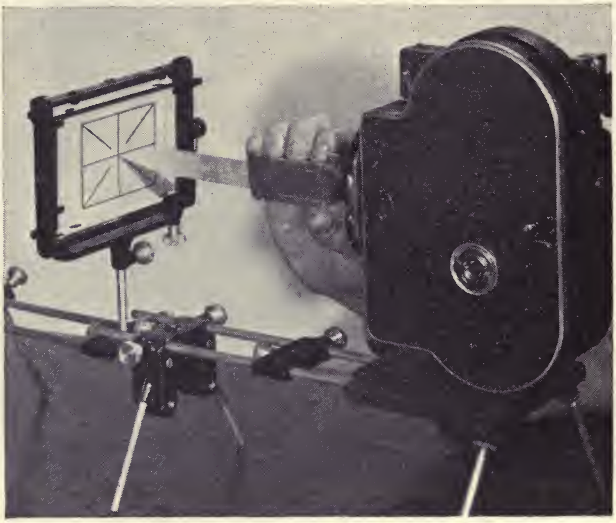


FIG. 2.

Special effects may be accomplished by the manipulation of the platen assembly in connection with the various accessories supplied with the device. The following special effects may be obtained: wipes, double exposures, split-screen shots, flip-flop titles, swing-around titles, zoom titles, and scroll and rolling titles. In addition to these special effects and special types of titles by the use of the several mattes supplied with the device, outline and matte photography also may be accomplished. The device may be used in conjunction with almost any 16-mm or 8-mm camera and is designed so that it will not place any restriction on the user from obtaining a limitless number of combinations. Usually as the user becomes more familiar with the device many new ideas suggest themselves.

RECENT AMERICAN STANDARDS FOR 16- AND 8-MM EMULSION POSITION

The three most recent American Standards to appear in the new format are Z22.10, Z22.16, and Z22.22. The first two concern Emulsion Position in 16-Mm Silent and Sound Projectors, respectively, while the third is on Emulsion Position in 8-Mm Silent Projectors. With the exception of titles, which were brought up to date, they are identical with the previous standards which carried the 1941 approval date. The absence of change might imply that the emulsion-position situation has remained static over the intervenening years, but this is far from being the case. Actually, the question of whether the film emulsion in normal 16-mm projection should face the screen or the light source has been the subject of considerable discussion, particularly as regards sound release prints. Sixteen- and eight-millimeter silent films are a parallel problem but they are less important economically and are far less critical from a technical viewpoint, so whatever is adopted for 16-mm sound will probably be adequate.

Offenhauser[1] reviewed the history of the present standards pointing out that the question first appeared in 1924 when 16-mm reversal film was introduced in this country as a boon to the amateur motion picture maker. Contrary to 35-mm negative-positive practice, which yields a release print with emulsion toward the light source, an original reversal film, which is run in the projector as well as in the camera has the emulsion facing the projector lens. Apparently the standard was chosen without any formal consideration having been given to the fact that at some later date duplicates made by the same reversal process might be contact-printed with the emulsion of the "dupe" necessarily facing the projection lamp (the nonstandard position). When that practice became a reality both positions were of economic importance but brought attendant conflicts into the field of standards and at the same time developed a serious practical compromise of sound quality.

The conclusion which Offenhauser drew early in 1942 was that neither emulsion position could be standardized out of existence because "For the duration of the war, at least, both emulsion positions will continue to be of great importance".

At the end of the war when all motion picture standards were reviewed by ASA Committee Z22 for possible revision, those on emulsion position were referred to a subcommittee of Z22 and the entire question reopened much as Offenhauser implied it might be almost four years before.

At one time in its deliberations the subcommittee considered a recommendation that those standards be dropped entirely because industry practice and the collection of negative, reversal black and white, reversal color, and all possible combinations of dupes and release prints presented so thorny a problem that any standards appeared almost valueless. Since ignoring the problem was no solution, the subcommittee agreed to accept argument for and against the existing standards in an attempt to reach some definite and reasonable conclusion.

J. A. Maurer* presented a thorough up-to-date analysis of the problem to the subcommittee in June, 1946, and because it covers the subject in complete detail his report is presented here in its entirety.

METHODS OF PRODUCING 16-MM RELEASE PRINTS IN RELATION TO THE QUESTION OF EMULSION POSITION

Two American Standards, Z22.10-1941 (16-mm silent film) and Z22.16-1941 (16-mm sound film), are in existence at the present time. Both of these standards call for the emulsion surface of the film to face the projection lens. This is the exact opposite of the emulsion position which has been standard in the 35-mm industry.

This emulsion position is the one almost necessarily obtained by the exposure of reversal film in a camera, and was, therefore, the emulsion position of all of the large amount of amateur 16-mm film in existence at the time these standards were first proposed, around the year 1932. At that time it was believed that amateur sound film made in single-system 16-mm cameras would be an important factor, and the sound-film standard in particular was set up to conform with the emulsion position necessarily obtained on sound films made directly in the camera.

Substantially all of the optical-reduction printing equipment built since 1932 has been designed to print through the base of the 35-mm picture and sound-track negatives so that the reduction print has the emulsion position specified in Z22.16.

* J. A. Maurer, Inc., New York, N. Y.

For convenience in what follows, this emulsion position, specified in Z22.10 and Z22.16, will be referred to as "standard", and the opposite emulsion position will be referred to as "nonstandard".

Following is a list of the processes that are in commercial use at the present time for producing 16-mm motion picture positives for projection.

A. Black-and-White Picture Processes

1. Reversal film exposed directly in the camera is used for projection. As explained above, this film necessarily has the standard emulsion position.

2. The positive film obtained as in (1) is printed by contact on reversal duplicating stock. This gives nonstandard emulsion position. This process has been extensively used in the past, but at present is used for "work prints" rather than for release.

3. A 16-mm negative made in the camera is printed by contact. This produces nonstandard emulsion position. This process is used principally for record purposes, as, for example, the photographing of football games for the benefit of college coaching staffs. It is not suitable for production work where a large number of release prints is needed because 16-mm negative films suitable for use in the camera are easily abraded and, even when handled with extreme care, rarely yield more than about 50 satisfactory prints. Another disadvantage of the process is that negative splices show plainly on the screen, since the printed image of the cut edge of the splice is an almost entirely clear white line in the print.

4. Thirty-five-millimeter negatives are printed by optical reduction. This process can be set up to produce either standard or nonstandard emulsion position in the print, but practically all existing printers have been designed to produce standard emulsion position.

5. A fine-grain 16-mm negative is printed by contact from a 16-mm original reversal positive, and this 16-mm negative is used to print the release positives. This process yields standard emulsion position. It is the procedure generally followed by successful 16-mm producers since it minimizes the visibility of mechanical defects such as dirt and scratches in the original positive, these defects being reproduced black in the release print, instead of white as in the release print made from a 16-mm original camera negative, and it is capable of yielding a very large number of good release prints, since many fine-grain negatives may be printed from an original reversal positive.

The introduction of the fine-grain negative step makes possible control of contrast and the introduction of optical effects in the film laboratory without contributing noticeably to graininess in the release print. The quality of the release print is superior to that obtained by Method 2.

6. A fine-grain 16-mm negative is printed optically from a 35-mm positive, and this negative is printed by contact to produce the 16-mm release print. The same process is also used when double negatives are made on 32-mm width film for release printing on 32-mm width film which is afterwards split to 16-mm. This method, since it involves an optical-printing step, may be made to produce either standard or nonstandard emulsion position, but the equipment actually in existence is designed to produce release prints having standard emulsion position.

B. Black-and-White Sound Track

1. The sound track is recorded directly on 16-mm reversal film in a single-system camera. This necessarily produces standard emulsion position.

2. "Direct positive" sound track is recorded either on sound-recording film or positive printing stock. Since some existing recorders may be operated with the film moving either from left to right or from right to left, around the recording drum, either standard or nonstandard emulsion position may be produced at will.

3. Sixteen-millimeter sound-track negative is made in the recorder and is printed either by contact or optically to produce the 16-mm sound-track positive. When the direction of film motion is reversible in the available recording equipment, this process may be made to produce either standard or nonstandard emulsion position. When optical sound-track printers are used, a further element of flexibility is available which permits the printing of negatives having either emulsion position to produce prints having either emulsion position.

4. A sound-track negative is made by contact printing from a direct positive sound track produced as in *B-2*, and this is used to print the 16-mm sound-track positive. This process has been used commercially only in connection with equipment using 32-mm width film. Because of the reversibility of film motion in the recorder, the process may be operated so as to produce either standard or nonstandard emulsion position in the release print.

5. 35-mm negative sound track is printed by optical reduction to

produce the 16-mm release-print sound track. Since an optical step is involved, the process can be set up to produce 16-mm prints having either emulsion position, but existing reduction printing machines have been designed to produce standard emulsion position.

6. A 16-mm sound-track negative printed by optical reduction from a 35-mm sound-track positive is used to print, by contact, the 16-mm sound-track positive. This process is generally used with 32-mm width film. Since an optical-printing step is involved, it may be made to produce either emulsion position in the release print, but existing apparatus has been designed to produce standard emulsion position.

C. Color Processes for Picture

1. Direct photography on reversal-type color film produces a projection positive having standard emulsion position.

2. The original 16-mm color positive (made in the camera) is used for contact printing of duplicates on reversal-type color film. This is the only process of real commercial importance which produces nonstandard emulsion position. At the present time, it is the best method available for producing good-quality 16-mm release prints in color.

3. A 16-mm color duplicate printed from the original color positive is used to print, by contact, a "second-generation" duplicate on reversal color-duplicating film. This produces standard emulsion position, but necessarily involves some sacrifice of accuracy in color reproduction. The process is used when it is necessary to produce very large numbers of release prints of a given color subject.

4. A 35-mm color positive is printed by optical reduction on 16-mm reversal-type color-duplicating stock. This process may be used to produce either standard or nonstandard emulsion position, but existing apparatus has been so designed that when printing forward it produces prints having standard emulsion position. If the 35-mm color positive is threaded "tails up" and printed backward, the nonstandard emulsion position is obtained. Printing backward in general is done only when it is necessary to produce inserts to be spliced together with prints made by Method *C-2*.

5. A 16-mm positive produced as in (4) is used to print, by contact, "second-generation" 16-mm color duplicates. As explained above, this process may be made to produce either standard or nonstandard emulsion position.

D. Color Sound-Track Processes

1. Sound track is recorded directly on 16-mm reversal-type color film as in a single-system 16-mm camera. This process necessarily produces standard emulsion position.

2. Sixteen-millimeter "direct positive" black-and-white sound track, made as in *B-2*, is used to print, by contact or optically, 16-mm release-print sound track on reversal-type color-duplicating stock. Because of the elements of flexibility provided in existing recorders as explained under *B*, this process may be operated so as to produce prints having either standard or nonstandard emulsion position.

3. A 16-mm positive sound track printed from an original 16-mm negative sound track is used to print the release-print sound track on reversal-type color-duplicating stock. This process may be operated so as to produce either standard or nonstandard emulsion position.

4. A 35-mm positive sound track is printed by optical reduction on 16-mm reversal-type color-duplicating stock. Being an optical process, this may be operated so as to produce either emulsion position,but existing equipment has been designed to produce standard emulsion position. Nonstandard 16-mm prints are obtained by threading the negative "tails up" and printing backward. This must be done when the sound track is to be combined with picture duplicates made by Method *C-2*.

5. Sixteen-millimeter black-and-white sound-track positive printed by optical reduction from 35-mm sound-track negative is used to print sound track on reversal-type color-duplicating film. Since the 16-mm positive track produced on the optical reduction printer normally has standard emulsion position, the contact print on the color film has nonstandard emulsion position and is suitable for combination with color picture prints made by Method *C-2*.

The above listing does not include a number of processes that are today either experimental or not in commercial use because the necessary equipment is not yet available. The most important developments in this direction will be optical-printing equipment for release printing of both picture and sound from 16-mm original, and negative-positive color processes along the general lines of the Agfa color process used in Germany during the war.

It will be seen from the above survey that a large majority of the 16-mm prints produced today have standard emulsion position. The only commercially important process which produces nonstandard emulsion position is *C-2*, used in combination with *D-2*, *D-3*, *D-4*, or

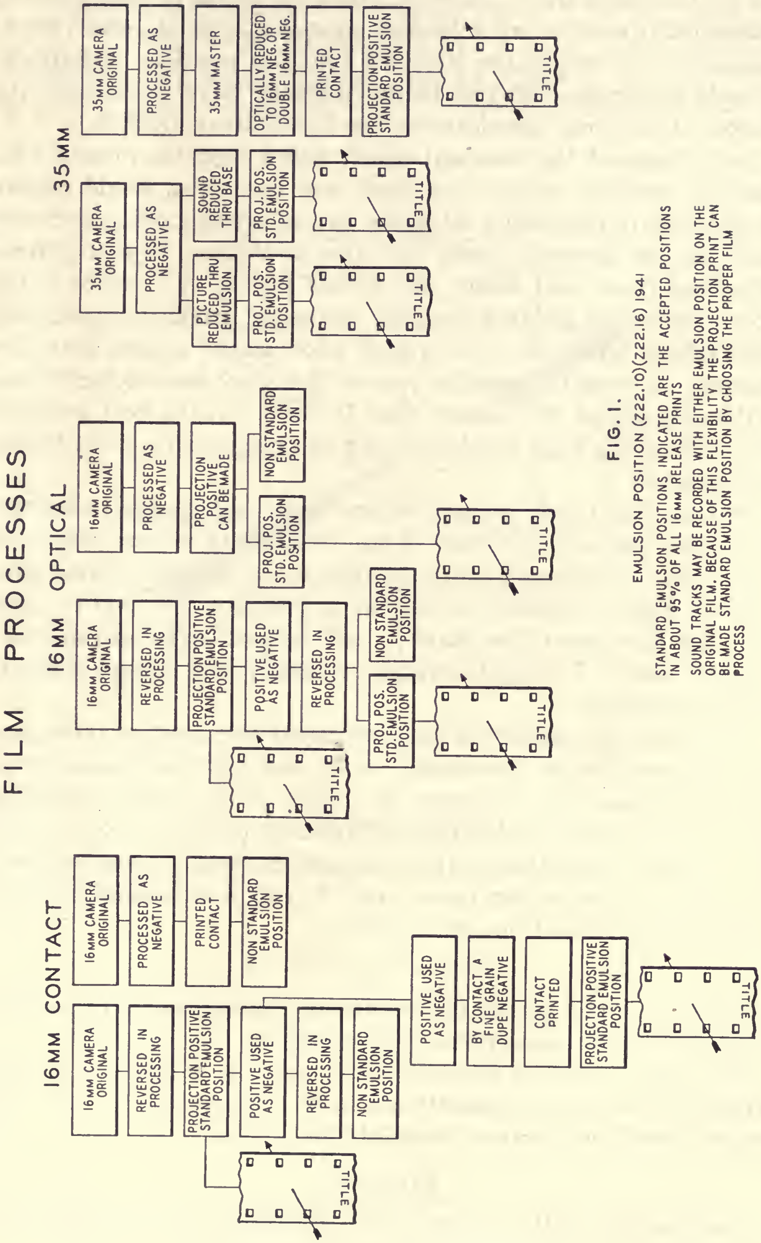


FIG. 1.

EMULSION POSITION (Z22.10)(Z22.16) 1941

STANDARD EMULSION POSITIONS INDICATED ARE THE ACCEPTED POSITIONS IN ABOUT 95% OF ALL 16MM RELEASE PRINTS

SOUND TRACKS MAY BE RECORDED WITH EITHER EMULSION POSITION ON THE ORIGINAL FILM. BECAUSE OF THIS FLEXIBILITY THE PROJECTION PRINT CAN BE MADE STANDARD EMULSION POSITION BY CHOOSING THE PROPER FILM PROCESS

D-5 for the sound track. The fact that up to the present time no commercially satisfactory substitute process is available, which would produce prints having the standard emulsion position, probably is the only reason that workers in the industry have questioned the wisdom of retaining American Standards Z22.10 and Z22.16.

Any change of the standard which would make the present nonstandard emulsion position standard, and vice versa, would require modification of practically all of the optical-printing equipment now being used to produce 16-mm reduction prints from 35-mm picture-and-sound track, and would also outlaw process *A-5*, which is the most widely used and best available method of producing black-and-white release prints when the original photography is done in the 16-mm size. It would also outlaw process *C-3* which has a definite place in the industry at the present time, because it is the best available way of obtaining large numbers of release prints from a given 16-mm color original.

On the other hand, optical-printing equipment for the production of 16-mm release prints from 16-mm originals of picture-and-sound track is now under development in at least two different laboratories, and will almost certainly be a commercial factor by 1948 or 1949. Once this equipment is available, it will be possible to operate processes *C-2* and *C-5* so as to produce release prints having standard emulsion position.

It may also be pointed out that a change of the standard at the present time would make it necessary, or at least highly advisable, to refocus the sound-optical systems of almost all the projectors now in use. On the other hand, retaining Standards Z22.10 and Z22.16 will give a commercial situation that will steadily improve, since within a few years we may expect to see prints having nonstandard emulsion position eliminated from the industry.

• • •

A diagrammatic outline of the current 16-mm processes was made by E. A. Bertram and appears here as Fig. 1.

The above material was submitted and the proposal was duly ratified by action of Committee Z22, in its approval of the three revised Emulsion Position Standards that follow.

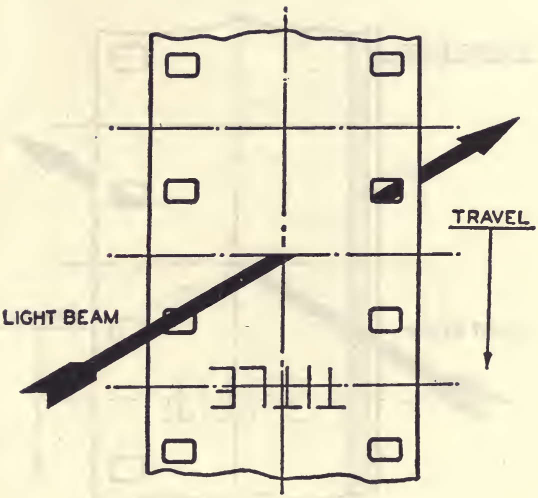
REFERENCE

[1] OFFENHAUSER, W. H.: "A Review of the Question of 16-Mm Emulsion Position", *J. Soc. Mot. Pict. Eng.*, 39, 2 (Aug., 1942), p. 123–135.

American Standard

Emulsion Position in Projector for Direct Front Projection of 16-Millimeter Silent Motion Picture Film*

ASA
Reg. U. S. Pat. Off.
Z22.10-1947
Revision of
Z22.10-1944



Drawing shows film as seen from the light-source in the projector.

1. Emulsion Position

1.1 The emulsion position in the projector shall be toward the lens, except for special processes.

2. Speed of Projection

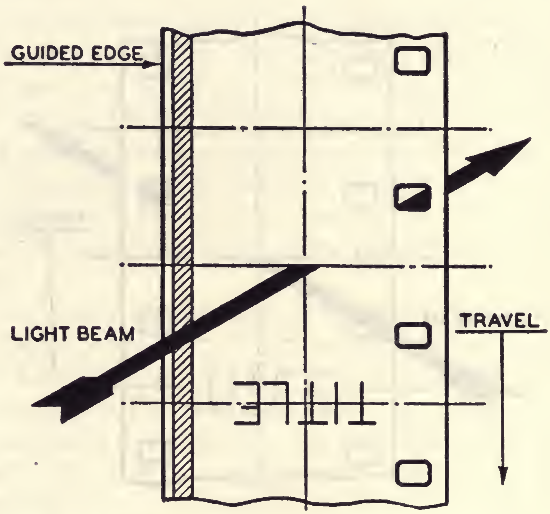
2.1 The speed of projection shall be 16 frames per second.

*The title of this standard is the only revision from the 1941 edition.

American Standard

Emulsion and Sound Record Positions in Projector for Direct Front Projection of 16-Millimeter Sound Motion Picture Film*

ASA
Reg. U. S. Pat. Off.
Z22.16-1947
Revision of
Z22.16-1941



Drawing shows film as seen from the light-source in the projector.

1. Emulsion Position

1.1 The emulsion position in the projector shall be toward the lens, except for special processes.

2. Speed of Projection

2.1 The speed of projection shall be 24 frames per second.

3. Distance Between Picture and Sound

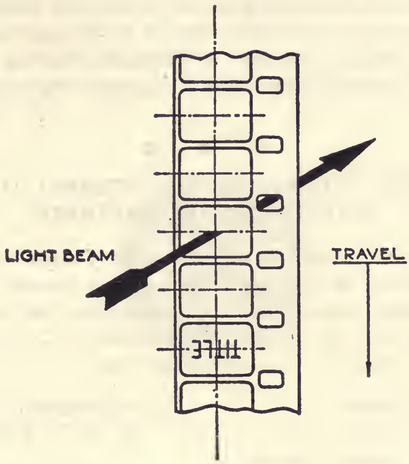
3.1 The distance between the center of the picture and the corresponding sound shall be 26 frames.

*The title of this standard is the only revision from the 1941 edition.

American Standard

Emulsion Position in Projector for Direct Front Projection of 8-Millimeter Silent Motion Picture Film*

ASA
Reg. U. S. Pat. Off.
Z22.22-1947
Revision of
Z22.22-1941



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SOCIETY ANNOUNCEMENTS

PACIFIC COAST SECTION

F. E. Carlson of the General Electric Company Lamp Division presented a paper on "New Developments in Mercury-Arc Sources for Motion Picture and Television Studio Lighting" at the September 30, 1947, meeting of the Pacific Coast Section. He discussed development work on mercury-arc lamps in England and ran some interesting Technicolor tests comparing this new light source with the carbon arc. He also demonstrated one of the new 5-kilowatt lamps.

Since this was a subject of a great interest to the motion picture industry, members of the American Society of Cinematographers, the International Photographers, and the Studio Electrical Technicians were invited to attend this meeting.

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CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

28, 9 (Sept. 1947)

We Operate the Biggest Camera in the World (p. 312) P. Ivano

British Kinematography

19, 9 (Aug. 1947)

The Carbon Arc: Its Characteristics and Properties (p. 37) F. S. Hawkins

Unit Specialization in Kinema Equipment (p. 47) S. B. Harrison-Swingler

Arc Lamp Conversion Equipment (p. 49) J. C. Milne

International Photographer

19, 9 (Sept. 1947)

Trivision (p. 20)

International Projectionist

22, 9 (Sept. 1947)

Sound-Film Projection in Sweden (p. 8) S. Dahlstedt

Low-Reflection Coatings on Glass (p. 10) W. P. Strickland

Journal of the Biological Photographic Association

16, 1 (Sept. 1947)

A Motion Picture of Models of Motile Bacteria (p. 3) A. Pipjer

High Speed X-Ray Motion Picture Studies (p. 15) I. Rehmau

Radio News

38, 4 (Oct. 1947)

Television Camera Tubes (p. 46) H. J. Seitz

The Recording and Reproduction of Sound, Pt. 8 (p. 51) O. Read

Tele-Tech

6, 10 (Oct. 1947)

Making Reverberation Time Tests in Broadcast Studios (p. 44) L. P. Reitz

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